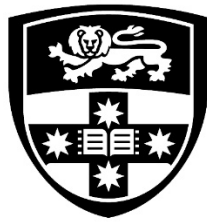


**COMPUTATIONAL MEASURE & EVALUATION OF  
VISUAL INFORMATION IN COMMUNICATION  
ARTEFACTS IN URBAN DESIGN**

REBEKAH ARAULLO



THE UNIVERSITY OF  
**SYDNEY**

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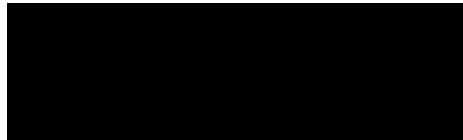


# Statement of Original Authorship

This is to certify that to the best of my knowledge, the content of this thesis is my own work. This thesis has not been submitted for any degree or other purposes.

I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged.

Signature:



Date : 30 May 2025

## BIOGRAPHY

Rebekah Araullo worked as a Senior Urban Designer in Major Projects, a department in the City of Canterbury Bankstown, local government area within the Sydney Metropolitan Area. The City of Canterbury Bankstown comprises a geographic area of over 110 square kilometres and is the second most populous local government in NSW. At the time of writing this thesis, her work focused on urban renewal, city transformation strategies, and active transport and integrated transport initiatives. She was involved in the delivery of state significant infrastructure such as the Southwest Sydney Metro train station precincts within the local government area, the design alignment of the East West Pedestrian & Cycling Link infrastructure, and spearheaded the Campsie Complete Streets project to support the transformation of the local town of Campsie into a strategic centre.

# Abstract

Design visualisations do not often convey information efficiently to stakeholders in urban design. While visual artefacts are intended to convey key aspects of a project, the process of tailoring them to support efficient collaboration and decision-making, particularly in the early phase of urban design, remains largely underexplored. A visual communication artefact is an object containing graphical information used in design for visual communication. This can be plans, sections, 2D, 3D or higher dimensional graphical information. These artefacts are constructed and manipulated graphical data required for understanding, and decision-making. However, there is no universally accepted standard for the appropriate level of detail, leading to continued reliance on traditional formats. This often results in a mismatch between the information provided and the needs of stakeholders. Despite ongoing advancements in information and communication technology, visual communication artefacts are often treated as standard one-size-fits-all tools. Without a deliberate process for calibrating the level and types of detail that can be conveyed to suit different stakeholders, these artefacts may present excessive or irrelevant data, complicating one's task of extracting critical information. This can delay stakeholders' ability to interpret information effectively to reach shared understanding, particularly when their priorities, technical expertise, or perspectives vary widely.

To explore this vulnerability, this research presents an algorithmic system for measuring visual information in an artefact, and evaluating this based on its fitness to meet the specific information requirements of individual stakeholders. The research highlights inefficiencies in current practice and aims to reduce these by exploring how graphical information can be more aligned with stakeholder needs. Additionally, the research contributes to emerging areas of inquiry focused on measuring aesthetics, and analysing and evaluating graphical data using computation. Aesthetics in this research leans on George Stiny and James Gips' definition in *Algorithmic Aesthetics* to describe how a piece of work can be described, interpreted and evaluated and with questions about how new works can be created.



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# Chapter 1: Introduction

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## 1.1 BACKGROUND

Urban design projects often involve stakeholders with diverse objectives and viewpoints. These projects can vary in scale, from local public domain upgrades to large regional infrastructure initiatives and frequently carry added layers of social and political complexities. Communication in the early phase of urban design development rely on effective visualisations to ensure efficiency in the design collaboration and to easily reach shared understanding throughout the process. They play a critical role in conveying key aspects of the project and are required to enable an optimised process for informed decision making. Visualisations —such as drawings in 2D plans, cross-sections, and 3D or higher-dimensional models— are communication artefacts made through constructed and manipulated graphics that capture and present design information associated with real world values. Drawing conventions in architectural design have long served as the primary visual communication artefacts across built environment professions. Regarded as the cornerstone of design communication and serving as a universal language to diverse stakeholders, these artefacts are intended as a one-size-fits-all communication standard for designing, mapping, analysis, collaboration and planning. However, the level of detail and types of graphical information conveyed in artefacts do not always fit the needs of all the stakeholders in a project. Without a deliberate process for calibrating the level and types of detail, these artefacts may present excessive or irrelevant data, complicating one’s task of extracting critical information.

As stakeholders involved in urban design projects can have widely varied priorities, technical expertise and perspectives, disparity in deciphering artefacts can be expected. This often results in delays in stakeholders’ ability to interpret information effectively to reach shared understanding. There is also no universally accepted standard to determine the appropriate level of detail and the types of graphical information that needs to be contained in

artefacts, one that will meet individual stakeholder needs effectively. This often results in a mismatch between the information contained in the artefact and the information needs of stakeholders. The continued reliance on conventional visual communication practice and the lack of indication as to appropriate levels of detail and types of graphical information in artefacts mean urban design communication requires further investigation. The process of tailoring visual communication artefacts that would suit individual diverse stakeholders, and that can improve communication processes and decision-making, can be characteristically deficient without further exploration. Regardless of sophistication and despite ongoing advancements in information and communication technology, visual communication artefacts in urban design projects can be considered primarily functioning as generic forms of design communication. With the lack of specificity needed to convey nuanced information, artefacts instead provides a level of detail that may be inappropriate (Metral, Falquet & Vonlanthen, 2007; Cronan, Trammell & Kliskey, 2022). Excessive or irrelevant data can obscure essential information and can lead to longer processing times. Stakeholders face the challenging task of deciphering these artefacts from a subjective standpoint, to extract the specific information they need. This indicates that visual communication artefacts are often only partially meaningful to individual stakeholders during the design process.

As urban design is collaborative and interdisciplinary (Mandanipour, 1997; Cuthbert, 2007; Lang, 2009; Carmona, 2021), the process requires a high degree of consensus due to its focus on the public realm. This makes urban design projects inherently variable and less organised, and leverages a diverse array of skills and knowledge. Although an urban designer is a technical expert, other experts are involved in the urban design process. Each one will have a different visual information standard. In practice, there is no consensus among project stakeholders as to what is considered appropriate level of visual detail. Therefore, ways to measure visual information can improve understanding in this regard. The varied methods and analytical perspectives of stakeholders, means generic visual communication artefacts are insufficient to effectively address their specific needs. Stakeholders come from diverse

backgrounds and possess different levels of technical expertise. They are interested in different aspects of the project and different types of information (Metral, Falquet & Vonlanthen, 2007). The degree to which design information is processed relies on effective visual communication, which must convey relevant details and be presented in a way that is easily understood (Metral, Falquet & Vonlanthen, 2007). Fundamentally, the relationships and interactions among stakeholders in the urban design process depend on effective visual communication.

The increasing ubiquity of information and communication technologies (ICT) continues to expand opportunities for graphic representation, leveraging technological advancements to find new ways to improve visual communication artefacts in urban design. Despite this, tailoring visual communication to meet the needs of individual stakeholders remains underexplored (Cronan, Trammell & Kliskey, 2022). Practical methods for assessing the effectiveness of visual artefacts are currently limited, as is a framework for comparative analysis and optimal evaluation (Cronan, Trammell & Kliskey, 2022). Consequently, determining and measuring how efficient visual communication artefacts remain a significant challenge. Meanwhile, the rapid growth of cities means urban design is increasingly complex creating pressure to enhance communication efficiency, as urban design projects exhibit considerable variability across multiple dimensions. They differ in scale, ranging from macro-level city wide initiatives to micro-level interventions within parts of the city. They also vary in shape as they encompass the amorphous spaces between buildings, the forms of the buildings themselves and configurations within the urban landscape. Additionally, projects vary in design focus: some prioritise social aspects, such as fostering vibrant communities, while others focus on utilitarian outcomes, like road networks. The end product of an urban design project may range from a visionary masterplan design to a present-day streetscape urban intervention. Several factors also play a significant role. Project economics vary widely with budgets ranging from tens of thousands to hundreds of millions. Physical conditions also differ, influenced by numerous environmental and technical factors. Policy constraints vary across levels of

government, and political factors impact projects at community, local and regional levels. Furthermore, urban design projects differ significantly in stakeholder perspectives and the required specialised skills of those involved. No two urban design projects are identical. This means that while precedents provide valuable insights, the inherent variability of projects would benefit from a design approach that is adaptable. Consequently, under these conditions, effective communication becomes more important and a fundamental component, the glue that can synthesize diverse perspectives, and support the economic viability and the social success of urban design projects.

The universal challenge of communication in light of these factors, indicates that urban design labours under a conventional visual communication practice that is less stakeholder centric. In the absence of clear metrics to ensure information alignment with stakeholder requirements, artefacts are often created for general consumption, making them largely speculative in meeting individual stakeholder information needs. Typically, artefacts are deemed suitable for use in the early urban design phase when the visual information they contain aligns with design information requirements and contributes to demonstrating compliance with planning regulations and building requirements. The central focus in this visual communication paradigm is to align with the conventional process which overlooks the need to more closely satisfy the specific information requirements of individual stakeholders, which at this point lacks a framework for understanding and measurement. The methods for assessing how well the conveyed information aligns with stakeholder needs are limited. Without an effective way to evaluate communicative impact, optimising artefact development remains largely speculative. Therefore, establishing a framework for understanding visual information and for forming a coherent communication logic creates a foundation for exploring solutions to this universal challenge.

## 1.2 RESEARCH AIM & OBJECTIVES & HYPOTHESIS

The purpose is to measure visual communication and evaluate its efficacy by developing a framework that compares graphical content with stakeholder information needs, formalises evidence-based principles, and introduces a new analytical tool for evaluating their communicative value. It evaluates how the information matches the needs of the intended audience of the communication.

This research hypothesises that if graphical information embedded in visual communication artefacts—such as drawings, diagrams, and 3D or higher-dimensional models—can be systematically quantified and assessed against explicit information requirements of stakeholders, then the communicative value of those artefacts can also be effectively measured. Further, if both the graphical information and the stakeholder requirements are logically consistent and expressed using comparable value types, the process can support a rule-based approach that can enable consistent, evidence-based evaluation of the artefact's communicative value.

The research proposes two main questions:

- 1) how can visual information contained in an urban design communication artefact during the design process be graphically analysed and quantified?
- 2) how can stakeholders' visual information requirements be made explicit and expressed using the same value parameters to analyse graphical content in artefact?

These hypothesis requirements were achieved through the completion of the following research objectives:

- *Research Objective 1: Examine how a visual artefact can be graphically analysed exploring a framework that will allow explicit measurements.*

The research investigated how graphics can be quantified and measured. Significant work in this area identifies concepts from the Algebra of Shapes and explores graphical information attributes by George Stiny as a framework for quantifying graphical data. The research demonstrates that visual information can be decomposed into basic graphical elements for statistical data analysis, producing quantified and measured numerical data for explicit comparative processing and evaluation.

- *Research Objective 2: Formulate a systematic analysis to rationalise visual information with relation to urban design logic to ensure the process is contextualised.*

The research reviewed relevant literature and work related to urban design logic and aesthetic evaluation. Although Kevin Lynch's visual theory involving *path, edge, node, landmark, and district* is not without criticisms in literature, the research finds this sufficient as basis for classification of urban design elements. Using this to rationalise urban design aesthetics represented in visual graphics, is a shift in perspective from real world experience. It also allows the flexibility to use the classification across different scales. For instance, an Edge can refer to the river in a city map or a street kerb in a local context plan. Likewise, a landmark can mean a great tree in a square or the square in a town. The classification of path is also beneficial in allowing graphical elements to be associated with the notion of movement, as the concept of path implies movement, a critical aspect in urban design communication.

- *Research Objective 3: Investigate an appropriate method of inquiry that accommodates computational processes for an analysis and evaluation framework.  
Can a computational system be built using available mainstream tools?*

The research reviewed Algorithmic Aesthetics and found it appropriate to use as a rigorous method of inquiry. It can provide the framework for the research activities and data processing involved in the formulation and development of calculations within the research schema. Using Microsoft Excel Spreadsheet, the computational system prototype was developed by adopting the Algorithmic Aesthetics framework to create the schema for the analysis and evaluation processes of the research. The system incorporates calibration mechanisms to facilitate user specificity in assigning values and computation formulas, accommodating variations in artefact styles. A calibration mechanism is also included to address changes in stakeholder profiles and requirements, along with a mechanism to enable adjustments of objects and urban elements as focal points for review. As a rule-based system, data flows through the system in one direction, and structured with network components for a coherent framework underpinned by urban design principles and graphical information logic. For greater adaptability and flexibility, the system is designed so that components can be adjusted or replaced. This framework design ensures that changes to the system can easily be managed and do not compromise the integrity of the overall system.

- *Research Objective 4: Test the system using typical artefacts in urban design projects that have diverse stakeholders to demonstrate system functionality.*

To validate the methods presented, the system prototype was tested using four typical samples of artefacts in the experimentation and to demonstrate how the system works. The sample artefacts are in 2D formats and featured urban design focused on micromobility infrastructure in the Sydney metropolitan area. The results of the system are in two phases.

Phase one shows how much data is contained in the artefact providing an explicit measure and value for each data type. Phase two shows a score and rating of the artefact to indicate how well it performs to meet information requirements across the stakeholder group.

### 1.3 RESEARCH SCOPE

The scope of the research focuses on developing a system prototype that will measure data by employing graphical data analysis and computation to statistically quantify the visual information contained in artefacts. The measured data is assessed for its communicative effectiveness in meeting stakeholders' information needs and evaluated for its overall acceptability. This process explores the use of quantitative theories related to aesthetic measurement, focusing on the quantification process that will rationalise design information to identify discrete graphical data. It involves decomposing an artefact to examine specific graphical features and their descriptions, establishing a logic to measure data, assign values and evaluate their relevance. The processes of quantifying data, assigning values and assessing relevance are integrated into the system prototype which is developed using George Stiny and James Gips' *Algorithmic Aesthetics*: a framework designed to facilitate a systematic approach for aesthetic evaluation. "*Aesthetics is concerned with questions about how existing works of art can be described, interpreted and evaluated and with questions about how new works of art can be created.*" (Stiny & Gips, 1978). Accordingly, this research defines computational aesthetics as a form of reasoning concerned with the description, interpretation, and evaluation of existing works of art. In this regard, art refers to visual communication artefacts in urban design. Computational, by definition, is "*involving the calculation of answers, amounts, results, etc.*" (Cambridge Dictionary, 2025). This research will use statistics, by counting,

adding and multiplying (computational) to describe, interpret and evaluate the artefact. The research focuses on the evaluation of the artefact. It does not propose to replace the representation styles currently used in practice. But to demonstrate clearly how to identify, organise, count and measure graphic data, diagrammatic representation is used in the experiments.

The system is made up of two phases, phase 1 the analysis phase and phase 2 the evaluation phase. The analysis phase manages the operations for analysing the artefact. The automated result of phase one are data values in numeric form and is a measure of visual information contained in the artefact under examination. The result of phase one is the input to phase two which is the evaluation phase. It manages the operations for evaluating the artefact for its effectiveness in meeting defined information requirements of stakeholders. The automated result of phase two consists of a score and a rating as the evaluation result. The evaluation determines whether the artefact is deemed acceptable or inappropriate for each stakeholder and quantifies the percentage of data considered acceptable or inappropriate. As the research focuses on the evaluation of an artefact, it does not focus on how the artefact is created, as it considers that anyone can develop visual representation.

This research precedes the work about improving drawing capacity. The method of how to improve drawing capacity is not in the scope of the research. The implication that improvement can be made is a byproduct of the research, as indicated by the results of the system. This research also overlooks the fact that the artefact is part of a set of complementary drawings intended to be viewed simultaneously, as it focuses on the moment in time when a person invests their attention to understand one single drawing.

### 1.3.1 SEEING AND EMBEDDING

In phase one the system is presented with an artefact to be examined. As digital object recognition is not within the scope of the research, the quantification process of rationalising visual information to identify discrete graphical data involves reviewing the artefact and manually collecting data for statistical purposes. Once the data is collected and logically categorised, the statistical analysis method in the system is designed to automatically assign values to the data based on their relevance and spatial dimensions.

In addition, for the purpose of adapting the system to meet a variety of analysis conditions, a calibration mechanism is integrated into the system. This will allow users to adjust calculations, providing the flexibility to define specific conditions for artefact analysis. It also enables users to customise how values can be assigned based on graphical style requirements. The calibration mechanism not only facilitates the computation process in the system or how values can be calculated, it also establishes the parameters that govern these value calculations. For instance, users can evaluate an artefact based on how it prioritises visual appearance, that can range from photorealistic imagery on one end to more technical drawings on the other. Prior to examination of the artefact, the system can be calibrated. By allocating greater values to graphical attributes that can produce the desired visual effect, the process of analysis can be nuanced and tailored to one's analysis requirements. The thesis alternates the use of visual 'artefact' and visual 'representation'. The former is when visual information, such as a drawing is referred to as an object made by a person such as urban designer. The latter is when the visual information, such as the same drawing is referred to as information that is observed or consumed by a person, or a stakeholder. These terms are not contradictory, rather a nuance to describe visual information.

### 1.3.2 USING URBAN THEORY AS INPUT FOR VISUAL FRAMEWORK

The process of decomposing artefacts to examine specific graphical features, requires a framework to logically identify and describe these in the context of urban design. Analysis of visual works can be considered arbitrary without a structured guide for their review and examination, as visual works possess limitless aesthetic possibilities when analysed without a clear framework (Hoenig, 2005; Birkhoff, 1933). This feature that defines a framework is designed as an Input parameter in the system. The framework used in this research to test the system can be replaced with other valid urban frameworks. For the first system testing, the research uses Kevin Lynch's visual theory to address this issue and to ensure that evaluations are relevant and coherent within the context of urban design. Kevin Lynch's urban elements of path, edge, node, landmark and district (Lynch, 1960) will form a set of objective aesthetic criteria. This will provide the means to develop a taxonomic strategy for identifying, selecting and object categorisation of graphical data that can be examined in the artefact. The research also introduces an addition to this category, namely 'zone', to refine the system's analyses and variables list. The process starts by associating available graphical objects depicted in the artefact with Lynch's urban elements. While the objects are categorised according to this framework, they are cross-tabulated based on their geometry and graphical attributes, and quantified accordingly, forming the basis of the system's graphical logic and statistical analysis method. This feature is designed as another Input parameter in the system which can be replaced by other valid graphical logic.

For the first system testing, the research uses George Stiny's *Algebra of Shapes* and graphical information attributes (Stiny, 1980) as the basis for graphical logic in statistical system analysis. The research will test the system analysis that will measure visual information of typical samples of visual communication artefacts. The system will produce a numerical value for each urban element data contained in the artefact, thereby providing a logical measure

of visual information relevant to urban design. The research focuses on 2D visual information because it is much simpler to introduce the concepts and explain the process using 2D, as it is still the most common format used across practice. The research also discusses that dimension serves as a parameter in the system.

### **1.3.3 STAKEHOLDER & BASIC VISUAL OPTIMISATION**

Phase two of the system involves how the artefact can be evaluated for its fitness to meet the communication requirements of each stakeholder. Enabled by a calibration mechanism in the system, stakeholder requirements are variables that need to be established as part of the system set up prior to running the system. This defines which of the urban elements are associated with information the stakeholder needs. As this research is not about communication between urban designers but communication involving the urban designer and other stakeholders, this process is not prescriptive as information needs can vary, thus the system allows this to be calibrated to suit different stakeholders. This will be carried out manually, as an automated profiling of stakeholders to describe their communication needs is not available and not within the scope of the research. To provide input for testing the system, the task entails manually designating the urban elements that are most pertinent to each stakeholder. Consequently, the task primarily depended on a general understanding of each stakeholder's role and expertise.

Although visual optimisation falls outside the scope of this research, in addition to testing the system using sample artefacts, the research carries out an experiment to construct a manipulated version of the artefact for the purpose of making a comparison to elicit further insights to this process. The manipulated version of the artefact is a reconstruction of the required graphical data with the intent to align with stakeholder information requirements. This

version shows an improvement in the artefact's score and rating, categorically demonstrating that visual information can be more nuanced and customised to meet the information needs of stakeholders and deliver communication benefits in urban design.

#### **1.3.4 SYSTEM TESTING WITH URBAN DESIGN PROJECTS**

To test the system, this research experiments with four visual communication artefacts. Each artefact is typical and was used during the early design phase of an urban design project that focused on delivering micromobility infrastructure in dense town centres within the Sydney metropolitan area. Each project involved a redesign of the existing street network to accommodate micromobility infrastructure within the roadway. In dense town centres, crossing and intersection points are highly contested spaces crucial for the movement of pedestrians, vehicles and proposed micromobility devices. How these are conveyed in artefacts and understood generally can be challenging. Although these projects are considered complex due to several factors including design conditions and requirements, social, environmental and political impacts as well as having the involvement of a diverse array of stakeholders in the technical design and decision-making process, the four artefacts under examination represent typical visual communication used in current stakeholder design collaboration.

Each artefact introduces feature variability for testing the system. The first variation is project scale, encompassing small-scale urban interventions and a large-scale geographic design plan. The second variation relates to views, including plan and elevation views. The third variation relates to level of detail, ranging from less detailed visual representations to more technical ones. As a start, this provides a sufficient level of variety to test the system's effectiveness in evaluating typical visual communication artefacts.

Although the system is designed in principle to accommodate higher dimensional data, the scope of the research is limited to testing the system using 2D artefacts. Evaluating 3D and higher dimensional simulations is not included in this study as 3D artefacts were not available in the projects during the course of this research. However, the system allows for the further development of these features to enable the evaluation of higher-dimensional artefacts in future.

## **1.4 RESEARCH OUTLINE**

This section concludes the introduction of the research and illustrates the thesis outline. The research is structured and described according to chapters which are summarised below:

### ***Chapter one***

The first chapter introduces the research highlighting key points related to knowledge gaps and contextualising the study. This chapter also outlines the scope of the research and identifies the research aim, hypothesis and objectives, providing an overview of the research.

### ***Chapter two***

The second chapter is dedicated to the literature review. It begins with an examination of relevant literature concerning urban design communication and, more broadly, visual communication techniques and artefacts used in urban design. Additionally, it includes an analysis of the Algebra of Shapes and graphic information attributes, exploring their graphical concepts and practical applications. The chapter further reviews relevant theories on quantifying aesthetics, addressing how urban design artefacts can be deconstructed into their graphical data. Finally, it assesses Algorithmic Aesthetics, detailing how this framework can

be adopted into the research methodology, thereby providing a theoretical foundation for the research.

### ***Chapter three***

The third chapter presents the methodology of the research, providing a comprehensive overview of the framework and specific instructions for the operational processes involved in the system. It includes a detailed description of the research schema that employs the Algorithmic Aesthetics framework. The chapter elaborates on the formulation of statistical data analysis, highlighting the application of the Algebra of Shapes within the calibration mechanisms. Furthermore, it outlines the computations utilised in various aspects of the system, including data value calculation in the analysis, relevance calculation, penalty calculation and the production of results related to artefact scoring and rating.

### ***Chapter four***

The fourth chapter is dedicated to the research experiments and is organised into distinct sections. It begins with an introductory overview, followed by four experiment sections corresponding to each of the four urban design visual communication artefacts under examination. Each experiment includes a detailed statistical data analysis and evaluation of one artefact, along with two additional tests designed to manipulate the artefact to demonstrate the system's capabilities and explore how the artefact's score and rating can be improved. After each experiment, a comparison is provided that includes the original artefact, the first test and the second test, resulting in a total of three evaluations per experiment. Given that there are three evaluations for each of the four experiments, the research comprises a total of twelve

artefact evaluations. The experiments serve to demonstrate the functionality and capability of the system, as well as test the system's fitness to evaluate a diverse array of 2D visual artefacts.

### *Chapter five*

The fifth chapter focuses on the experiment results, findings, and evaluation of the hypotheses, organising the content accordingly. The sub-section on experiment results begins by presenting a tabulated analysis of the results for all twelve artefacts. The chapter discusses the outcomes of each experiment in detail, highlighting key insights derived from the analysis. Additionally, it examines various aspects of the system, providing valuable observations regarding its functionality and overall impact on the results. The sub-section on research findings details the insights related to the theories implemented in the research, including observations on the tools utilised during the experiments and the development of the algorithmic aesthetic schema. Furthermore, it explores findings associated with the application of Kevin Lynch's theory for aesthetic quantification, as well as findings relating to the selected case artefacts. The final sub-section evaluates the hypotheses in relation to the findings, discussing key points that demonstrate how the research met its hypothesis requirements. It highlights the evidence that supports and substantiates the findings, as well as the extent to which the hypotheses were validated. A summary concludes this chapter.

### *Chapter six*

The sixth chapter provides a conclusion to the research highlighting the contributions made and discussions relating to future work.

# Chapter 2: Literature Review

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This chapter opens with Section 2.1, which introduces the challenges associated with visual communication in urban design projects. This overview draws upon a review of relevant literature and previous efforts in the field to contextualize this research in relation to the current state of knowledge in this area. The section also includes review relating to communication conventions in urban design. Section 2.2 explores visual data in urban design. Section 2.3 introduces the Algebra of Shapes and Graphic Information Attributes. Section 2.4 discusses reviews relevant literature on the quantification of graphical aesthetics whilst Section 2.5 examines the applicability of Algorithmic Aesthetics for use in the research. Section 2.6 concludes this chapter.

## 2.1 INTRODUCTION

Urban design projects are inherently complex (Mandanipour, 1997; Metral, Falquet, and Vonlanthen, 2007; Cuthbert, 2007). They encompass a high level of variability and involve ongoing efforts that address all parts of the urban fabric, a colossal task to imagine. Hence, urban design is a popular topic of discourse. It's been asserted that as a product "urban design refers both to the design of cities and settlements as a whole and to the design of some parts of urban areas" (Mandanipour, 1997). Further, holistically as a process "...urban design as a continuous process of shaping places, fashioned in turn by shifting global, local and power contexts" (Carmona, 2021). More specifically, its intent has been described as the "manipulation of the concrete elements of distance, material, scale, view, vegetation, land area, water features, road alignment, building style, and numerous other items that make up the natural landscape and the built environment" (Sternberg, 2000), and more broadly, "...a

profession that sets out to shape the spatial or physical environment” (Sternberg, 2000). As well, from a practical perspective “urban design synthesises the work of architects, landscape architects and civil engineers and the integrated transportation and land use policy aspects of city planning” (Lang, 2009), and “urban design is typically collaborative and interdisciplinary, involving an integrated approach and the skills and expertise of a wide range of actors. They are rarely all embodied by a single professional” (Carmona, 2021).

Urban design involves numerous actors whose relationships and interactions are fundamentally reliant on effective communication. This serves as the backbone of successful urban design projects. Communication in urban design projects is multifaceted as it requires the ability to convey and elucidate both tangible and intangible elements through various means. Since the advent of computers in the last century, the effort to enhance communication for use in urban design and planning has been fervent. By the early 1990s, the exploration of computer-aided visualisation in urban design and planning had gained momentum, and premised upon three key assumptions: “1) to understand nearly any subject of consequence it is necessary to consider it from multiple viewpoints, using a variety of information; 2) understanding complex information about urban planning and urban design may be greatly extended if the information is visualised; 3) visualisation aids in communicating with others” (Langendorf, 1992). These principles remain relevant today, as the increasing ubiquity of information and communication technologies (ICT) continues to expand avenues for visual communication, leveraging technological advancements to improve visual communication in urban design and planning.

Despite notable advancements in urban design communication, significant challenges persist. Urban design projects often require a large degree of consensus, primarily because the projects involve the public realm. The urban actors involved come from diverse backgrounds and possess varying levels of technical expertise. As noted by Metral, Falquet, and Vonlanthen

(2007), urban actors “naturally use different terms and are interested in different types of information”, moreover, “...actors are not necessarily interested in all aspects of a project and may be interested in different aspects at different times”. This reflects the diverse priorities and perspectives of urban actors. The critical ongoing challenge in urban design visual communication is that the information conveyed tends to be generic, rendering it only partially meaningful to individual actors. This lack of specificity can hinder effective communication and understanding, ultimately impacting the project's success.

Recognising this communication challenge, Metral, Falquet, and Vonlanthen (2007) asserted that "an efficient communication tool for urban planning projects must provide each actor with the information that is relevant and present this information in a way that is easily understood." They further proposed the development of an ontology-based model that includes an adaptable interface component. This component aims to offer each actor a tailored view of the urban project that aligns with their specific profile and interests and will enable the user to define the best interface that will fit their needs. The ontology-based approach proposed entailed the use of explicit specifications to address the diverse elements within urban design. Given the complexity and variability of design elements, a formal vocabulary was deemed necessary. On this basis, they asserted that “formal means that some formal representation language has been used and so that the ontology is machine-readable and machine-processable” (Metral, Falquet, and Vonlanthen, 2007). In addition, the ontology-based model was proposed to include actor specific ontologies, in terms of viewpoints, and will include an ontology of themes, rendering the ability to align communication to their specific needs.

Despite initial works over a decade ago, progress in enhancing communication within urban design and planning has been slow. Tailoring visual communication to meet the needs of individual urban actors is inherently complex. The efficacy of visual communication remains difficult to determine and measure, as element representations in urban design involve present

realities and proposed future designs. This ongoing challenge is echoed by Cronan, Trammell, and Kliskey (2022), who note that "the current literature lacks a metric for gauging effectiveness and a framework for optimal evaluation of future scenario representations."

Their work focused on assessing the effectiveness of various representational approaches and developing a framework for evaluating compelling future scenario representation tailored to specific stakeholder groups. To achieve this, a structured stakeholder survey was conducted that involved the evaluation and ranking of graphics and representations across nine categories. Participants were asked, "In your professional opinion, how informative were the following graphics?" They ranked each graphic on a scale from 1 to 10, reflecting the informative level of each graphic. The results were calculated using an effectiveness scale, allowing for comparative analysis to determine the overall efficacy of the graphics and representations (Cronan, Trammell & Kliskey, 2022).

According to Cronan, Trammell, and Kliskey (2022), their work aimed at "developing a metric for evaluating the effectiveness of scenario representations (sic) can provide valuable assessment within projects as well as a framework for content delivery". The intention behind this proposed framework closely aligns with that of the ontology-based approach, which seeks to tailor communication to the specific needs of individual urban actors. This suggests that the challenge of effectively addressing diverse stakeholder requirements in urban design communication remains unresolved, highlighting the need for continued efforts in this area.

One theme that is salient in communication study is that the field of communication continues to grow, now at a speed beyond the capacity of an average scholar can process (Craig, 2008). From the perspective of urban design, communication among various actors in urban design projects is increasingly complex, influenced by continued advancements in information and communication technology (ICT) and the rapid growth of urban areas.

## 2.1.1 COMMUNICATION IN URBAN DESIGN

### 2.1.1.1 Drawings

Traditionally ideas, design concepts and technical descriptions of the three-dimensional world that we live in are communicated using drawings of sections, elevations, plans and perspectives, primary views to describe a three-dimensional design concept. This has a long history that can be traced back to the start of the Renaissance period, during which Alberti formalised the strict conformity to drawings. His idea that design of a building is first composed in the mind, then translated into a graphic standardised code which include plans, elevations and sections. “Today’s construction drawings, a notational tool for the conveyance of technical information from designers to makers, are a modern cultural technology invented by Leon Battista Alberti in his treatise *On Building (De Re Aedificatoria)*, composed around 1452” (Carpo, 2011).

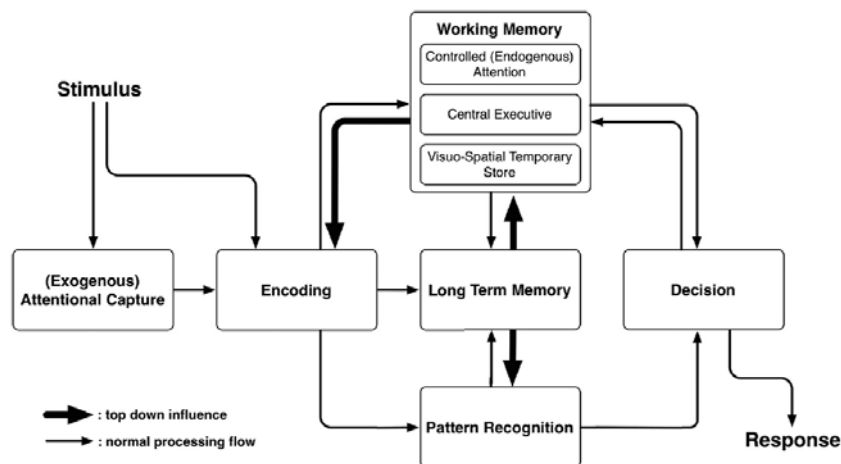
Predominantly, visual communication in urban design relies on line drawings, whether in traditional paper format or digital media, which continue to be utilised in contemporary practice. These drawings capture essential information to convey to project stakeholders, translating complex three-dimensional concepts into more accessible two-dimensional representations. While these methods are generally acceptable, the extensive packaging of design information and design iterations have been recognised as resource intensive. Given the critical role of visual communication in urban design projects, it is important to examine how digital communication artefacts can be more sustainable and can influence communication efficacy, as urban design is inherently reliant on the visual element or communication.

Alan B Jacobs, in *Great Streets*, identified key drawings which he illustrated used to provide comparable information about the physical qualities and designable characteristics of streets. These are plans, cross sections, dimensions, details, patterns, illustrations of urban

contexts. These drawings according to Jacobs permit urban designers and decision makers to efficiently compare and facilitate understanding of what great streets are (Jacobs, 1991). These communication artefacts have largely been considered the true sources of information relating to designs of buildings and spaces as they hold key information. Urban design communication relies on a variety of tools to support different stages of the design and planning process that can transfer the image of the city and future scenario representations into smaller hand-held consumable information.

Various digital communication solutions permeate contemporary urban design practice. Visualisations are employed not only for surveying and analysis but also for design development (Batty et al., 2001). However, it is crucial to note that research on the precise impact of both analogue and digital visualisations, as well as forms of communication in urban design and planning, remains underexplored. Additionally, the historical and current applications of visualisations are limited (Christmann et al., 2020). While visualisations are often assumed to enhance publicity, promote participation, and serve as evidence of collaborative design processes, these assumptions lack robust empirical evidence (Hasler, Chenal, & Soutter, 2017; Tambouris et al, 2013). Researchers have pointed out that these claims remain largely unexamined, emphasising the need for more rigorous investigation into the effectiveness and actual impact of visual communication methods in urban design projects. At the turn of the century, a significant distinction emerged regarding types of visualisations and their intended purposes. Forward visualisations, aimed at the general public, emphasise the aesthetic and visual attributes of design, while backward visualisations cater to professionals in the field with specialist skills (Batty et al., 2001). This distinction, however, is a little simplistic. It implies a clear divide between professionals, who are portrayed as having distinct needs, and the public, who possess a different set of requirements. While conventional drawings continue to be utilised, other forms of communication artefacts are gradually

becoming standardised. Consequently, there is a growing body of research focused on the application of computer-aided design (CAD) and emerging technologies for visualisation within the urban design field (Bieda et al., 2020; De Siqueira, 2022; Chen et al., 2023; Giaveno, 2021). This shift highlights the evolving landscape of visual communication and the need for tools that address the diverse needs of urban actors. As this research seeks to develop an effective method to analyse visual information, it is critical to understand how the traditional design communication that is based on compositions of partial representations of the design can be approached. Generally, drawings come in sets consisting of plans, sections and elevations that convey complementary information. The practical way is that a person will devote their time to digest this collective information by sequentially focusing on a single drawing at a time. A person will focus on a single drawing, commit information to memory and will synthesise this with the next drawing information and so on. This is reflected in Figure 2.1 that maps the process for reasoning and understanding, illustrating a human cognition framework for information visualisation (Patterson et al, 2014). As such, the research will evaluate a single artefact as a single input variable in the system. *“A key characteristic of the human visual system is that it can notice only a single item at a time when presented with a visual field that has multiple items”* (Thompson, 2023). Hence, this research will focus on the moment in time when the person invests their attention to understand a single drawing.



**Figure 2.1:** Human cognition framework for information visualisation. Source: Patterson et al (2014).

### 2.1.1.2 Descriptive Geometry

Descriptive Geometry is a well-established science since the 18<sup>th</sup> century, when Gaspard Monge first systematised the representation of three-dimensional shapes (3D) on the two-dimensional (2D) support of the drawing (Migliari, 2012), a similar process to Alberti's work *On Building (De Re Aedificatoria)*. It's been an essential tool and the basis of urban design visual representation. The interplay between 2D and 3D is typical for descriptive geometry and an ongoing process in urban design. In the same way the 3D world is captured into 2D, the 2D graphic can be extended to 3D using digital tools. It's a process since the dawn of the digital era in urban design.

Constructive Geometry is another related term to descriptive geometry. It is also a term used in computer graphics as since the early digital format was borne, (Ricci, 1973). The fundamental difference is that it deals with solid geometry, using mathematical computations, such as Boolean operations, to add or remove primitive geometric solids. Capturing and conveying spatial information is an aim in 3D visualisation, for a person to gain the ability to communicate and comprehend spatial objects, and the spatial environment from given principal views, such as top view like a floor plan, front and side views like elevations, and through this, gain an understanding of the geometric abstraction of shapes and understanding of spatial reasoning (Ricci, 1973).

The lack of methods for effective and efficient design process communication manifests as a struggle for Architecture, Engineering and Construction industry professionals (Senescu & Haymaker, 2013). Communication it seems is a key challenge as 2D design drawings attempt to communicate designs that are essentially spatial in nature. These spatial qualities are three-dimensional and at times carry time-sensitive information that is not easily captured in 2D formats. The practice of information modelling, or Descriptive Geometry, from Alberti to capture 3D logic into 2D formats is still central to the communication of designs that involve

our three-dimensional world. The premise that Constructive Geometry using Boolean operations manipulates shapes to remove or add geometric data in a digital environment is a notable process that can inform how digital information can be manipulated as required.

### **2.1.1.3 Geographic Information System**

Another information modelling that involves our three-dimensional world is the Geographic Information System (GIS). This involves geographic information and data related to the position of the Earth's surface. It captures data such as topography, landscapes, buildings, vegetation, bodies of water and streets, which references exact locations on Earth, which people use to understand the world we live in. GIS is commonly associated with a digital platform for the maintenance, recording and visualisation of geographic data, and is widely used in planning and landscape architecture. Jack Dangermond, the founder of the world's leading supplier of GIS software ESRI, has said that "GIS is making geography come alive. It condenses our data, information and science into a language that we can easily understand: maps" (Dangermond, 2012). However, the principles of GIS have long existed before its conception which has its origins tied with hand drawn cartography which transitioned to digital computer mapping in the 1960s. "The history writing of GIS is as motley as it is abundant written by many authors" (Carlsson, 2013). Before the digital process, graphical maps were developed with layers of information using rasters. Site characteristics in which data relating to topography, land use, demographics and such were organised as overlays, called overlay mapping (Tomlin, 2012). As a source of information that provides a concise representation of the surface of the earth, GIS has its purpose beyond its use as an analytical tool. GIS is also useful in design and planning and has also exposed new possibilities for urban design and landscape design. For design disciplines, GIS capabilities allow new perspectives of seeing, thinking and designing (Carlsson, 2013). Indeed, as current urban virtual modelling platforms rely on GIS data. Urban

virtual modelling can also be considered a form of virtual communication in which participants can share and collaborate on designs in the virtual space.

It would appear that overlay maps, GIS graphical imagery, Alberti's graphic standardised code of plans, cross sections and elevations, virtual 3D models are forms of visualisation for the purpose of communicating information about our three-dimensional world and a compendium of visual communication artefacts. They attempt to describe objects and spatial relationships that are not easy to grasp due to factors such as scale, GIS data layers as example, and time, in terms of design that doesn't exist yet, only as a concept, as well as location, in which a virtual model is useful for reference.

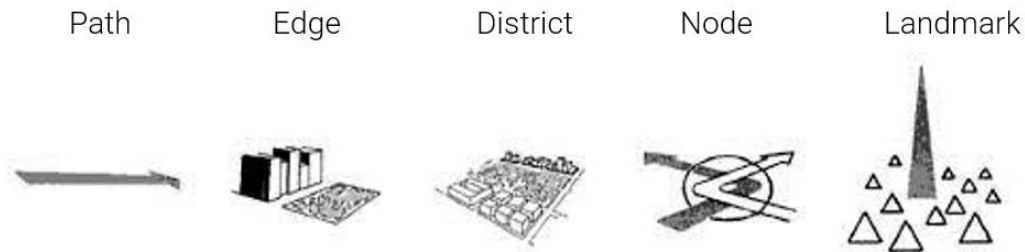
## **2.2 VISUAL DATA IN URBAN DESIGN**

This research will also need to examine established concepts and methods relating to design representation. These are recognised in the research as important to the analysis of communication artefacts. How space and movement representation can be communicated efficiently will also be explored. The following Sub-Sections highlights some basic techniques relating to space and movement communication. It also explores opportunities for improvement and for more nuanced information relating to movement in a design scheme. It highlights important concepts on the interdependence of space and time for communicating design that involves spatial articulation and movement in space using 2D drawings. Discussions relating to spatial and spatio-temporal dimensions are also included in this section.

### **2.2.1 URBAN ELEMENT COMMUNICATION**

In 1960, Kevin Lynch defined five elements of a city that still play a foundational role in current urban design and continue to influence theory and practice. These essential elements

are *Path*, *Edge*, *District*, *Node* and *Landmark* that are considered key components to create the overall structure and character of a city (Lynch, 1960). They are considered to define a person's mental image of cities as they define recognisable and coherent urban patterns, enhancing a city's legibility.



**Figure 2.2:** Urban design elements. Source: Lynch (1960).

To summarise: according to Lynch, paths can be streets, walkways, transit lines, canals and railroads. Paths may have specific spatial qualities and special identifications. They may also be used with activity along a street and become important features in several ways for customary travel. Paths have clear origins and destinations.

Edges act as boundaries between two phases or are linear breaks in continuity. For example, there are edges of development and land use, the side of paths that define a property boundary are edges. Park edges are also clear in this regard, and so on.

Districts can be visually identified as they are large areas with spatial and physical characteristics that determine it is spatially organised in a way that is understood, as some are grouped discretely on its own or some are interconnected or mentally seen as overlapping. The physical characteristics that help determine districts are the spaces and forms of building types, the topography and the movement and activity of the inhabitants, as well as details within and surrounding texture that adds to its identification. In today's notion of districts, they can even be different sizes of precincts that may hold special significance to people, as well, they can also be understood as town centres or whole suburbs.

Nodes are considered strategic focal points. They can be a place where people have organically come to congregate, they can be a high activity area such as a well-known café precinct, or a significant intersection or junction for vehicle or pedestrian movement, as such a train station in this regard can also be considered a node.

Landmarks are the points of reference in a city and can vary in scale. An example in Sydney is the Centrepont Tower or the Opera House.

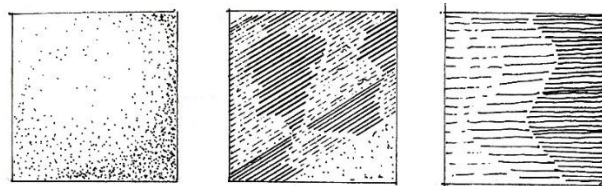
These are the *objects* that are critical in the practice of urban design and in the built environment in general. They require a special kind of language that can be used to communicate higher dimensional information and specific details about our physical three-dimensional world we live in. current methods to communicate critical details relating to these to be able to easily understand spatial concepts and relay them are inefficient as communication conventions have not changed since blueprints were adopted in 1842.

Unlike *edges, districts and landmarks* which can be captured in a still photograph and design intent specified precisely in the communication model of using plans, sections and elevations, the requirement and intent for *path* is harder to capture and communicate. This is because *path* relates to movement and direction. According to Lynch, *paths* “are channels along which the observer customarily, occasionally or potentially moves. They may be streets, walkways, transit lines, canals and railroads” (Lynch, 1960). It can be observed in Lynch’s *path*, that an arrow to indicate direction is used. It also needs to be acknowledged that in the same token, the arrow also indicates movement is involved. *Node* as well uses arrows as it relies on the efficacy of conveying *path*.

However, beyond the simplicity of identifying a *path*, direction and movement are qualities that are not easily and efficiently communicated. As well, unless there is an indication that a space captured within the view is a segment of a path and used for movement, the space

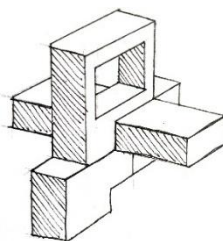
can easily be misinterpreted as a space that has a static function such as parking bay, garden, or public open space.

By convention, movement and direction have mostly been represented using symbols. A general direction is often included in design plans by using the north point symbol to indicate orientation of the space or the building. This guides the reader to understand information relating to environmental factors such as sun and shade. For more precise defined direction, arrows are also used which can identify the space as used for passing through or that movement occurs in the space. Arrows also show direction of wind, show direction of stairs and on pathways. Arrows are also used extensively to provide information on directions such as entry points and up or down motion. To convey more nuanced spatial information, traditionally colours or hatching and cross-hatching styles are used. Lines and dots are also commonly used to highlight variation and depth.



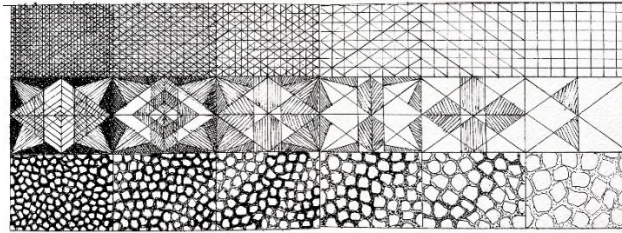
**Figure 2.3:** Drawing explorations using lines and dots to communicate space.

The use of hatching as well helps to understand spatial information such as orientation or how the object is positioned in three-dimensional space.



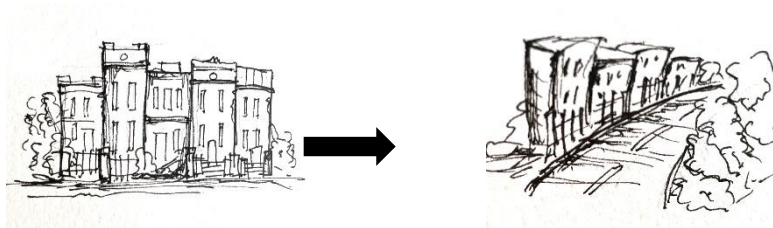
**Figure 2.4:** Drawing exploration using hatching to communicate depth.

Hatching is as well effective in communicating spatial information such as tone and depth when a gradient is applied from heavier to lighter or from dense to sparse.



**Figure 2.5:** Drawing exploration using density for gradients.

Streets, directions, and distance are also communicated using various techniques, some of which require re-orientation and applying perspective viewpoints to suggest movement.



**Figure 2.6:** Drawing exploration on orientation to show change from static to movement.

Movement on the other hand signifies change. It is a change from one position to another. *Merriam-Webster Dictionary* (2012) defines movement as the act or process of moving; a particular instance or manner of moving; a tactical or strategic shifting of a military unit; the advance of a military unit; action, activity; a series of organised activities working toward an objective; an organised effort to promote or attain an end; the moving parts of a mechanism that transmit a definite motion; the rhythmic character or quality of a musical composition; a distinct structural unit or division having its own key, rhythmic structure and themes and forming part of an extended musical composition; particular rhythmic flow of language; the quality of representing or suggesting motion; the vibrant quality in literature that comes from elements that constantly hold a reader's interest; an act of voiding the bowels; matter expelled from the bowels at one passage.

Without using arrow symbols, communication of urban paths such as streets, footpaths, or alleyways, where movement, distance and space can be conveyed using vanishing point

techniques, in which parallel lines appear to converge. This increases capital spatial information as it allows the reader to understand distance, space, and movement direction.



**Figure 2.7:** Great streets. Source: Jacobs (1995).

As movement is dynamic, it is harder to capture on a two-dimensional (2D) drawing of plan, section, and elevation. Hence, the concept of change from one position to another involves the element of time.

Conveying direction and time which are spatial qualities is not easy. The complexity lies in the notion that standard drawings of plans section, and elevation, commonly used throughout built environment practices which are static and frozen in time, need to be able to carry and convey information relating to movement in space and time which are non-static as they are dynamic.

### **2.2.2 SPATIAL DIMENSIONS**

Space and time relationship. As explored in the use of drawing techniques using hatching and perspective orientation, data relating to space is possible to convey. The framing and organising of the lines of streets and pathways converging to a vanishing point conveyed spatial information. Important concepts in urban design and the built environment such as *place*, a term which can be used to refer to an intangible concept relating to characteristics of a

designated three-dimensional space, can utilise these techniques to provide more descriptive information.

As well, the adoption of 3D modelling in the built environment introduced new ways to represent design. It allowed design practitioners and other built environment professionals to operate in a digital 3D environment. Understanding geometric dimensions and how geometry can efficiently represent real-world objects and information have become a practical competence in design practice. Spatial information of various dimensional space can be improved in a 3D environment to enable better understanding and communication of design intent and consequences. As such a 3D model is becoming a standard toolset in design representation.

In practice, it is understood that communication of dimensions uses the following mediums:

- 0D Zero dimension. This is usually represented by a point which can be conveyed using 2D communication artefacts of plan, section and elevation.
- 1D One-dimensional representation. A line is considered 1D which can also be conveyed using 2D communication artefacts
- 2D Two-dimensional representation, usually on print or digital screen. They are flat planar representations. Design plans, sections and elevations are 2D.
- 2.5D Two-and-a-half-dimensional representation are 2D that appear three-dimensional by using 2D perspective and layout. Video games develop 2.5D imagery.
- 3D Three-dimensional representation, usually digital imagery or a physical replica model. Augmented, virtual and mixed reality technology are usually in 3D space with either 2D or 3D objects.
- 4D Spatio-temporal models

However, in as much as 3D is able to communicate spatial information such as width, height, depth and distances in relation to its surroundings, it does not effectively communicate movement and temporal information, or time.

A 4D model on the other hand, according to domain experts is 3D with time (McKinney et al, 1996). This begs to be understood as space-making is dependent on the element of time. This is evident when time is observed through physical change. Erosion, movement, deterioration, climactic events are some examples of physical changes that convey time.

New methods of analyses using 4D have been found to be efficient in drawing insights in design and urban planning. An example is the use of simulations producing heat maps to improve analyses and designs for better environmental performance. The uptake of 4D in Building Information Modelling (BIM) analysis is also on the rise. It is the graphical simulation of the construction of a building design. Through this simulation construction activities are better scheduled in time sequences showing construction progress. This minimises wastes, makes better use of resources, improves construction management and improves communication with all involved. Through simulations the relationship of space 3D and time (4D) is activated.

It can be observed that communicating movement in the context of the built environment is dependent on the element of time, as spatial changes occur within a time sequence. In the same token it can also be observed that the communication of time is dependent upon representing spatial movement.

### **2.2.3 SPATIO-TEMPORAL DIMENSIONS**

Simply, in the context of built environment representation, movement information is reliant on the time data, and that the time data is critical to creating meaningful movement

information. Space and time are robust topics in physics and mathematics. Sir Isaac Newton's theory on laws of motion was a pillar in 19<sup>th</sup> century physics. His three laws of motion describe relations between a body or an object and forces that relate to inertia, acceleration, and action reaction. Inertia that a physical object is either at rest or continue to move unless acted upon by a force such as gravity. Acceleration relates to the object's rate of change of speed and direction, or velocity, that is proportional to the force acting on it. That forces have both action and reaction.

In 20<sup>th</sup> century physics, Albert Einstein's theories including his theory on space-time became the pillar that pioneered many key developments in the field. Space-time refers to the notion that space or place and time exist and occur together. Thus, a physical description that exists in the built environment is four-dimensional right from the beginning. It exists in a four-dimensional continuum that resolves in the three-dimensional continuum of space, with the one-dimensional continuum of time (Einstein, 1926). In this notion, 4D is 3D with time.

However, data relating to how time is usually conveyed and associated with 3D, is difficult to capture and arrange to be turned into meaningful information when using 2D plan, section and elevation. As plan, section and elevation are drawings on a flat paper or screen ready to be printed on paper, we consider these as lower dimensions than 3D, from 0D to 2D. To apply time and its relationship with lower dimensions in the context of this research that relates to representation, we can analyse and observe time through the following exercise. If time is conveyed through movement, the physical change of 3D is examined as that which can communicate the concept of time. Example, the rotation of a cube conveys the passing of time as it rotates through sequential changes in its positioning. How slow or fast, which is data of speed also increases our understanding of time. The velocity or the rate of change of the rotation, whether it is increasing or decreasing in speed can indicate a particular moment in time, whether it is at the start or the end of the cube's rotational movement. To test this further,

the concept of time can be explored by applying movement through the different dimensions. As the notion that 4D is 3D with time or that 3D is elevated to 4D when it is impacted by time, and the representation of time is reliant on movement, the following assumptions can be explored:

A. Does time elevate 0D to 1D? Such that,

$$0D \times \text{time (sequences of change or movement)} = 1D$$

B. Does time elevate 1D to 2D? Such that,

$$1D \times \text{time (sequences of change or movement)} = 2D$$

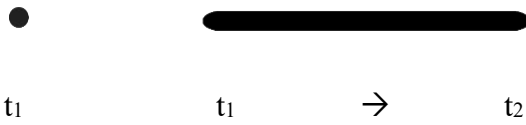
C. Does time elevate 2D to 3D? Such that,

$$2D \times \text{time (sequences of change or movement)} = 3D$$

#### A. 0D x time = 1D

Zero dimension in mathematics is considered to lack height, width and length and is simply represented by a point (Hazewinkel, 1989). The point is to indicate a position in space. Hence in this notion it is considered that 0D is a point. To examine the application of time on 0D, if the point has speed and direction (or velocity) as we established earlier that the communication of time is dependent upon representing spatial movement, we can observe that the point is mobile and moves from its position at  $t_1$  to a position at  $t_2$ . In effect a line is produced by the sequence of changes of the point's position along the path it travels. The line is considered the aggregate of all the positions of the point along the path. In this application of representing time ( $t$ ) which is reliant on movement of the point, it can be observed that 0D with time is 1D. With the presence of time, 0D is elevated to 1D.

Therefore,  $(0D + \bar{v}) \times \Delta \text{ time} = 1D$ .



Point                      Line as aggregate of tracked points

0D is zero dimension

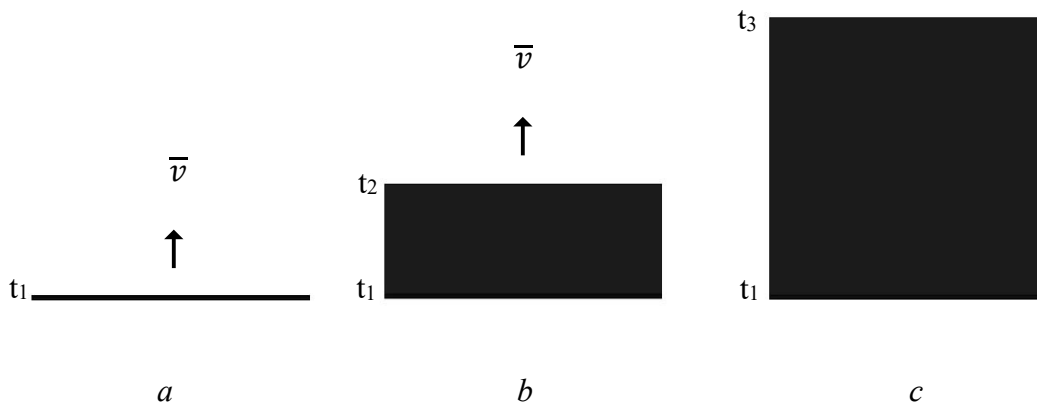
$\bar{v}$  is velocity

$x_{\Delta}$  is change in the value

B. 1D x time = 2D

As 1D below in *a* is represented by a single line, we take the line created previously to examine the impact of the element of time with 1D.

In the same fashion as time is communicated through movement, we can move the line in a direction from its position at  $t_1$  to position  $t_2$ . As the line is moved, the path it travels describes a surface represented by the 2D shape illustrated in *b*. The aggregate of all the position as the line is moved from position  $t_1$  to position  $t_2$ , represents a planar surface. Likewise in *c*, the 1D line is moved from its position at  $t_1$  to position  $t_3$  to create a 2D shape, a square, if the distance the line travelled is equivalent to the distance the earlier 0D point travelled.



Line                                      Planes as aggregates of tracked lines

Therefore, it can be observed that when the 1D line is mobile, movement is effected and which reflects the presence of time, 1D with time is 2D. With the presence of time, 1D is elevated to 2D. Therefore,  $(1D + \bar{v}) \times time = 2D$ .

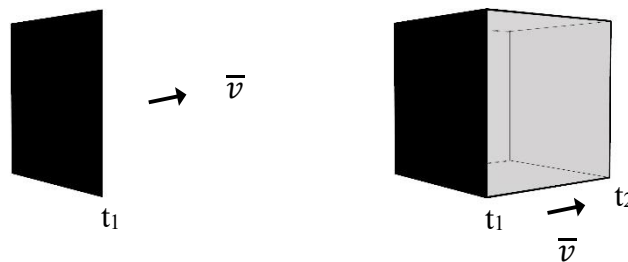
C. 2D x time = 3D



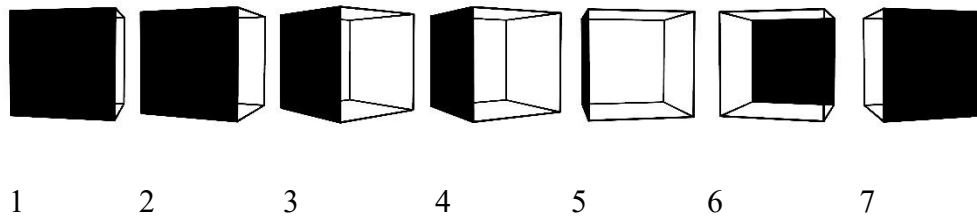
Given the two-dimensional square above, when engaged in movement as previously examined with 1D line, 2D is able to produce 3D information. The 2D square becomes a cube if it travels the same distance as both the 2D line and the 0D point had travelled.

The cube is the aggregate of all the positions of the square along its path. Hence, 2D with time is 3D. With the presence of time, 2D is elevated to 3D.

Therefore,  $(2D + \bar{v}) \times time = 3D$ .



To examine this cube further, when engaged in movement, sequenced snapshots can allow the observer better understanding of time and the cube's relationship with space. Using this 3D cube, time can be observed. To demonstrate, given the snapshots of the cube below, we observe that the cube is engaged in a time sequence.



The communication of time as discussed previously requires movement which can be conveyed through discrete data on direction and speed, or velocity. The sequence above from 1 to 7 using 3D with time or 4D, increases the level of information provided about movement. As the cube rotates clockwise it reveals its spatial characteristics in relation to time. It can be observed that the positions of the cube at 1 to 3 indicate a slower speed compared to the positions of the cube at 5 to 7. The cube's movement is described through this time sequence. The cube rotates in a clockwise direction and not with a constant speed, but it rotates gaining momentum starting at position 1 with increasing speed. In this regard movement is communicated and describes not only direction but also speed relative to space and time. It can be observed that nuanced information on movement can be communicated using 2D images on paper as illustrated above when the concept of a space and time relationship is applied.

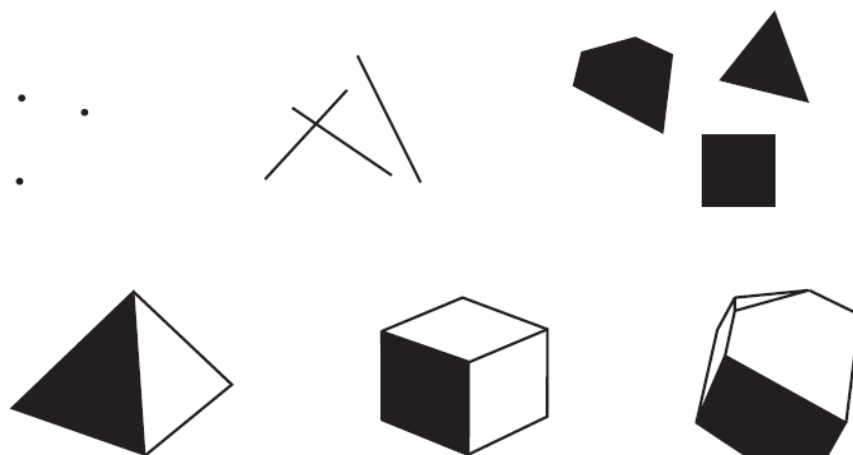
### 2.3 ALGEBRA OF SHAPES

Quantifying this nuanced information needs a framework to define specific elements of the imagery and shapes in designs, as well, be able to measure the characteristics and quality of the elements' attributes. In exploring spatial concepts with time and in relation to communicating information using 2D images, a scientific approach to representation is necessary in this regard. Representation using basic geometry of points, lines and planes have long been a topic of continued investigation and research in design and computation. Formalising design schemes using basic geometry, and the analyses of shapes have become

prolific since the widespread use of computers. These have their basis in earlier theories applying rules to geometry which have been foundational to many later findings.

George Stiny's study on shapes is a cornerstone in the field. The application of rules on geometric elements that has a vocabulary from which the rules are composed is called a grammar. As such any resulting design generated from the application of the grammar constitutes the language (Stiny, 1980).

Stiny explores how shapes are made up of basic elements of a single kind such as points, lines, and planes. Solids however he emphasises as just shapes containing lines and planes.



**Figure 2.8:** Basic elements. Source: Stiny (1980).

This is true as we observe that the spatial representations above of the 3D shapes are technically conveyed in 2D space. That is, three-dimensional representation or what appears to be a solid object is simply an arrangement of 2D planes and 1D lines.

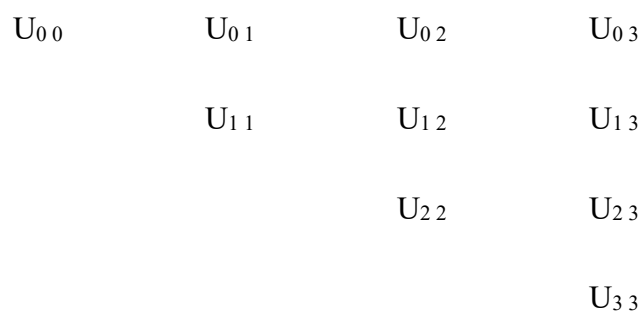
Shapes and dimensional space, and their relationship are further examined in terms of these basic geometric elements with Stiny's algebra of shapes. Algebra is a branch of mathematics that deals with variables using formulas with rules as techniques to calculate. To

simplify, algebra can be compared to elementary arithmetic of using basic operators of addition, subtraction, multiplication, and division to calculate. Algebra of shapes is conceived to calculate shape analysis and shape generation. It is calculating with shapes. In the algebra of shapes, instead of the use of numerals or letters, it uses the basic elements of points, lines and planes. As this involves arrangement in space, the relationship between space and shape must be established.

Based on Stiny’s definition in which three things go together to define algebras of shapes. First there is the shape itself that is made up of basic elements. Second is the part relation for shapes that includes Boolean operations. Third is the Euclidean shape transformation (Stiny, 1980).

He sets out that every shape in an algebra  $U_{ij}$  represents a finite set of basic elements. The index  $i$  represents the dimension of the element, and the index  $j$  relates to the shape transformation. He also explains that part relation compares shapes two at a time and the Boolean operations combine shapes – sum or addition, product or multiplication and difference or subtraction, as well as symmetric difference or product. As such, the transformations are operations on shapes that change them geometrically.

Stiny organises the  $U_{ij}$  algebra with respect to the indices which gives the following variation that sets out the hierarchy for a framework for shape grammars:



**Figure 2.9:** George Stiny’s algebraic expressions for shapes.

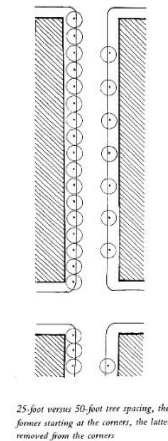
A shape according to Stiny is a finite set of geometric elements that are defined in dimension index  $i$ . Using the same elements described in the previous sub-section,  $i = 0$  represents points,  $i = 1$  represents lines,  $i = 2$  represents planes and  $i = 3$  represents solids. These geometric elements are manipulated in dimension  $j$ , in which  $j$  must be greater than or equal to  $i$ , i.e.  $j \geq i$ .

Given the geometry  $U_{ij}$ , some examples:

1)  $U_{01}$  in which index  $i = 0$  points, as 0D is a point, manipulated in dimension index  $j = 1$ , we can expect the shape geometry to be made up of points along a line as dimension index  $j = 1$  means the geometry occurs in 1D which is a line. As well, 1D data content is a length.



An example of this can be observed in the representation of trees on plan using points, in which the data content is length, translated from the data spacing of trees.

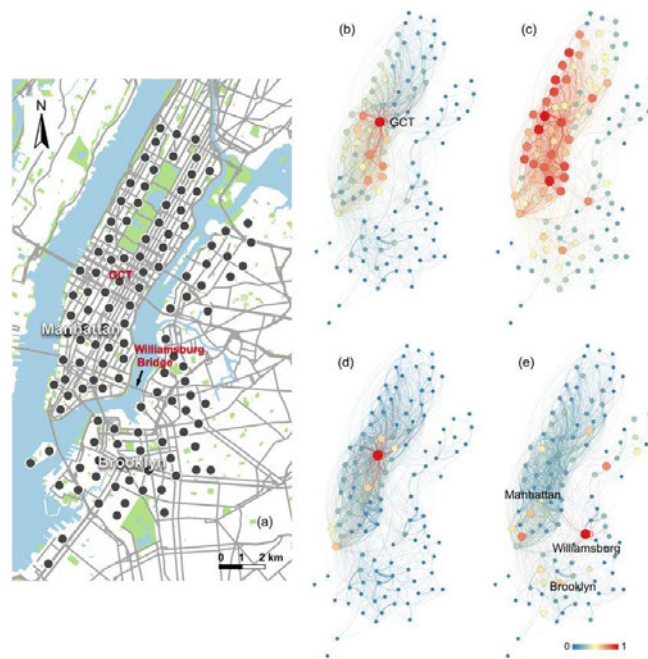


**Figure 2.10:** Spacing requirements for tree planting. Source: Jacobs (1993).

2)  $U_{0\ 2}$  in which index  $i = 0$  points are manipulated in dimension index  $j = 2$ , we can expect the shape geometry to be made up of points arranged in an area as dimension index  $j = 2$  means the geometry occurs in 2D which is a plane, with a data content of area.



An example of this can be observed in the representation of spatial distribution on plan using points, to derive data relating to area used in the study of bike-sharing station groups.

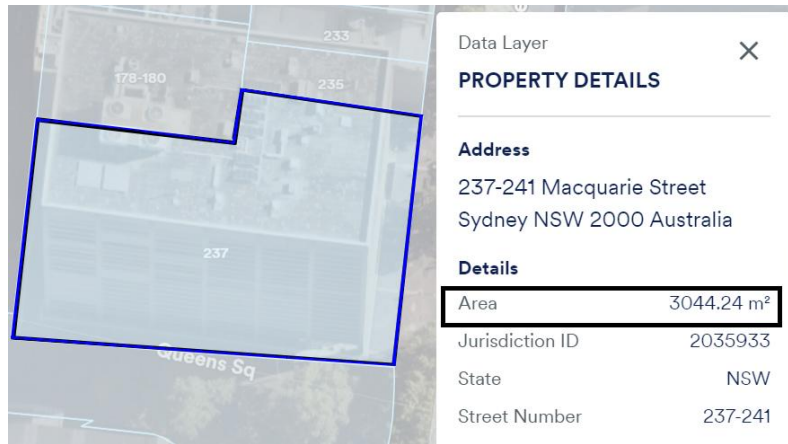


**Figure 2.11:** New York showing spatial distribution of bike-sharing stations and the areas the bike-sharing stations cover and service. Source: Yang et al (2020).

3)  $U_{1\ 2}$  in which index  $i = 1$  lines, as 1D is a line, are manipulated in dimension index  $j = 2$ , we can expect the shape geometry to be made up of lines only which would look like boundaries of shapes arranged in an area as dimension index  $j = 2$  means the geometry occurs in 2D which is a plane, with a data content of area.



An example of this can be observed in the representation of an area of a property using lines to represent the boundaries on plan.

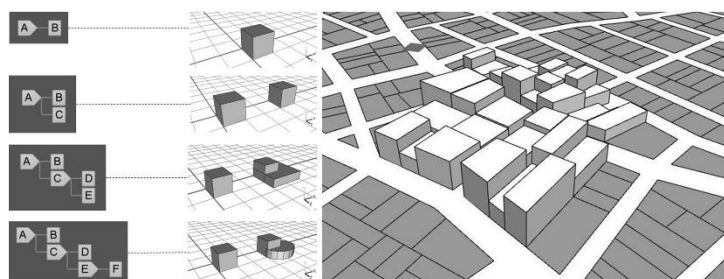


**Figure 2.12:** Area data in square meters for a property in Nearmap.

4)  $U_{2\ 3}$  in which index  $i = 2$  planes, as 2D is a plane, are manipulated in dimension index  $j = 3$ , we can expect the shape geometry to be made up of planar shapes arranged in a three-dimensional Euclidean space as dimension index  $j = 3$  means the geometry occurs in 3D, with a data content of volume.



An example of this can be observed in the analyses of urban densities using shapes to represent volumes of buildings in order to analyse the relationships of scale.

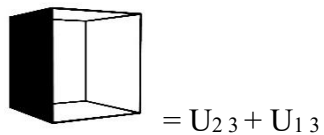


**Figure 2.13:** Volume of shapes to analyse scale in urban design. Source: Wang et al (2020).

In this way geometry and shapes can be understood, generated with logic and analysed in a systematic way. This is especially useful in complex designs as geometric elements can be analysed to represent shapes and their spatial properties that aid design representation and intent.

In such a way, basic geometric elements can be also useful in the representation of space as the hierarchy of shape algebras captures the notion of three-dimensional space.











Using the example in the previous sub-section, it can be observed the cube is:



The representation of the cube can be analysed as a geometric shape made up of a plane  $U_{2 3}$  and lines  $U_{1 3}$  in a Euclidean three-dimensional space.

In the same token, Lynch's urban design elements can be represented logically using geometric shapes. As such a simple representation may look like:

**Table 2.1: Algebraic expression depicting Kevin Lynch's urban elements.**

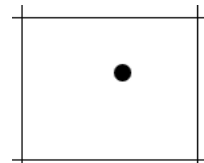
URBAN ELEMENT	NODE	PATH	EDGE	DISTRICT	LANDMARK
SPATIAL ELEMENT By Lynch					
GEOMETRIC SHAPES					
ALGEBRAIC EXPRESSION	$U_{0\ 0}$	$U_{1\ 3} + U_{2\ 3}$	$U_{1\ 3}, U_{2\ 3}$	$U_{1\ 2}$	$U_{2\ 2}, U_{1\ 2}$

$NODE = U_{0\ 0}$

Given the geometry  $U_{ij}$ , Node as  $U_{0\ 0}$  can be understood as

index  $i = 0$  represents the dimension of the element and

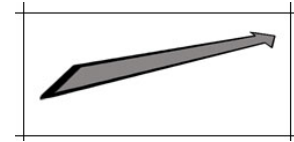
index  $j = 0$  relates to the shape transformation



As a result,  $U_{0\ 0}$  will always be a point. In this regard, the geometric shape used to communicate Node has the algebraic expression of  $U_{0\ 0}$ .

Lynch explains that Nodes are points representing strategic spots and intensive foci at which a concentration occurs. These concentration nodes are considered the focus and epitome of a district. These can be cores, junctions, events on a journey or path, moments of shift during which their importance may be the dominant feature.

$$\text{PATH} = U_{1\ 3} + U_{2\ 3}$$



Given the geometry  $U_{ij}$ , Path as  $U_{1\ 3} + U_{2\ 3}$  can be understood as

$U_{1\ 3}$  being,

index  $i = 1$  represents the line and

index  $j = 3$  relates to the shape transformation in a three-dimensional space

As a result,  $U_{1\ 3}$  is the set of lines or outline that make up the arrow in perspective

In addition,  $U_{2\ 3}$  being,

index  $i = 2$  represents the arrow shape made up of a plane and

index  $j = 3$  relates to the shape transformation in a three-dimensional space

As a result,  $U_{2\ 3}$  is the shape (brown) that makes up the shape arrow

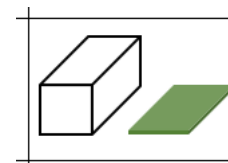
Combined,  $U_{1\ 3} + U_{2\ 3}$  represents the brown arrow with the black outline viewed in perspective or articulated in three-dimensional space. The geometric shape used to communicate Path has the algebraic expression of  $U_{1\ 3} + U_{2\ 3}$ .

$$\text{EDGE} = U_{2\ 3}, U_{2\ 3}$$

Given the geometry  $U_{ij}$ , the Edge as shown in the table above is represented with a comma between  $U_{2\ 3}$  and  $U_{2\ 3}$  unlike the Path which has + sign between  $U_{2\ 3}$  and  $U_{2\ 3}$

Similarly,  $U_{1\ 3}$  being,

index  $i = 1$  represents the line and



index  $j = 3$  relates to the shape transformation in a three-dimensional space

As a result,  $U_{1\ 3}$  represents the black outline of a cuboid in perspective

In addition,  $U_{2\ 3}$  being,

index  $i = 2$  represents the rectangular plane and

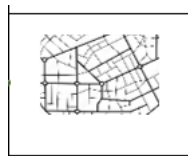
index  $j = 3$  relates to the shape transformation in a three-dimensional space

As a result,  $U_{2\ 3}$  is the rectangular shape (green) that represents the grass lawn

Unlike the arrow being combined,  $U_{1\ 3}$ ,  $U_{2\ 3}$  simply communicates a scene made up of geometries to bring meaning to this arrangement.

Lynch explains that Edges are the linear elements not used or considered as paths. Instead, these are the boundaries between two occurrences and organises spaces or elements in a city, they also hold together areas such as the outline of a city by water. The geometric shape used to communicate Edge has the algebraic expression of  $U_{2\ 3}$ ,  $U_{2\ 3}$ .

DISTRICT =  $U_{1\ 2}$



Given the geometry  $U_{ij}$ , District as  $U_{1\ 2}$  can be understood as

index  $i = 1$  represents the lines and

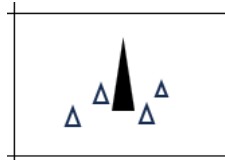
index  $j = 2$  relates to the shape transformation on a 2D or planar surface

As a result,  $U_{1\ 2}$  are lines simply arranged, manipulated in dimension index on a surface with no depth.

$U_{1\ 2}$  in which index  $i = 1$  are lines, as 1D is a line. The lines are manipulated in dimension index  $j = 2$ , hence we can expect the shape geometry to be made up of lines, which in this case compose to look like boundaries of shapes arranged on a plane as dimension index  $j = 2$  means the geometry occurs in 2D which is a plane. The geometric shape used to communicate district has the algebraic expression of  $U_{1\ 2}$ .

Arranged in such a way, the lines communicate a large area. According to Lynch, Districts are medium to large sections of the city and are usually communicated having two-dimensional extent. The lines represent how the city is structured and arranged. The lines can be the edges or paths within the city, arranged together they communicate districts or large areas. Maps are the most common example of this imagery.

$$\text{LANDMARK} = U_{2,2}, U_{1,2}$$



Given the geometry  $U_{ij}$ , Landmark as  $U_{2,2}, U_{1,2}$  can be understood as

$U_{2,2}$  being,

index  $i = 2$  is planar triangular shape to represent the landmark and

index  $j = 2$  relates to the shape transformation on a 2D which is a planar surface

As a result,  $U_{2,2}$  is a geometric shape that appears flat with no depth.

To add context to this,  $U_{1,2}$  being

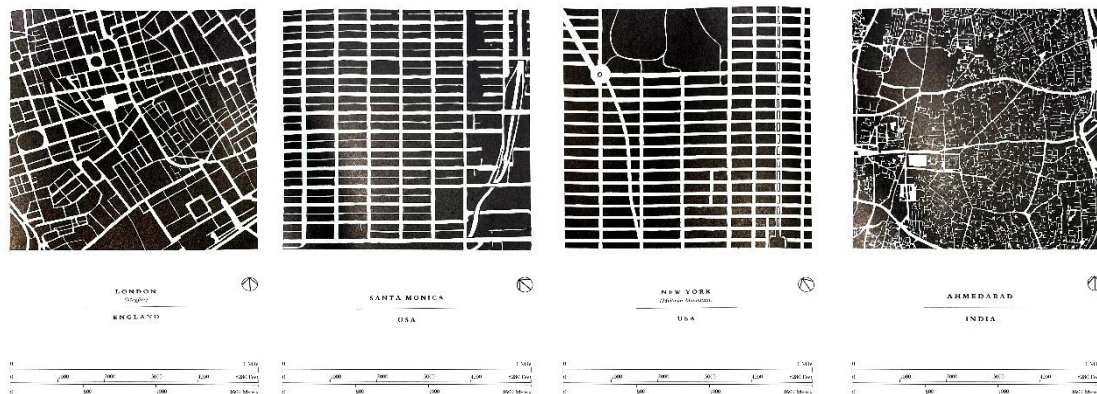
index  $i = 1$  are lines, as 1D is a line. The lines are manipulated in dimension index  $j = 2$

also relates to the shape transformation of the lines on a planar surface

Hence as a result  $U_{1,2}$  represents the outline of geometric shapes in this arrangement.

Combined, they are meaningful and communicate the importance of one element amongst other in the arrangement, the landmark. The geometric shapes communicating Landmark has the algebraic expression of  $U_{2,2}, U_{1,2}$ . According to Lynch these can be points of references in a city. They are singled out and can be a building, sign, or a mountain and symbolise a constant direction, as the landmark is an element viewed from a distance. As such, shapes can be brought together to represent a city. Shapes depict the order in which a city is organised. Wide streets, narrow bends, nodes, edges, barriers, and landmarks can be

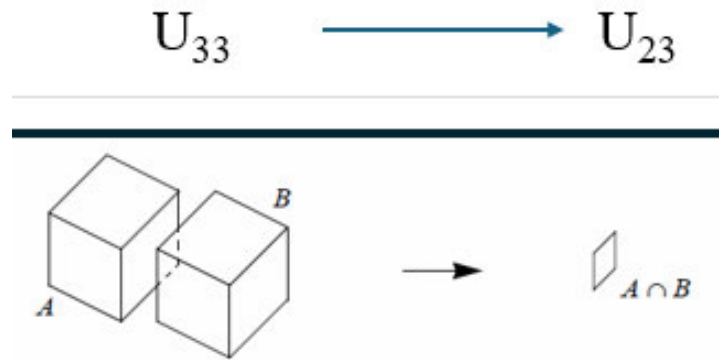
distinguished as illustrated in Figure 2.12. At a high level, a city form can be understood using planar shapes as seen in these maps, and which have the algebraic expression of  $U_2$ .



**Figure 2.14:** Street and City Patterns. Source: Jacobs (1995).

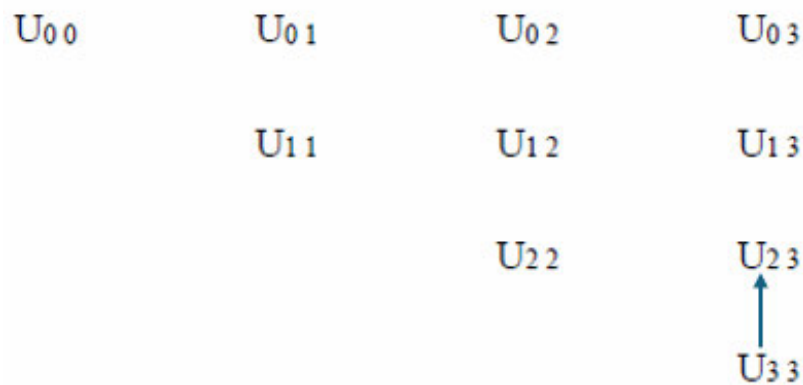
Building on earlier work, Rudi Stouffs has made further notable advancements in the development of shape grammar theory. His works on sortal grammars and algebra of shapes are mathematically rigorous and focuses on developing a unified algebraic model for shapes and geometric modelling (Stouffs, 1994; 2012). *“The global operations of sum, product, difference and symmetric difference on shapes, similar though not identical to the Boolean set operations of union, intersection, difference and symmetric difference on point sets, define an algebra of shapes”* (Stouffs, 1994).

While both Stiny and Stouffs contribute to the field of shape grammars, their works serve different purposes. Together, their works enrich the understanding and application of shape grammars in design and modeling practices. Stiny's work on the algebra of shapes is more aligned with the conceptual and creative aspects of design, offering a framework for thinking through shapes. In contrast, Stouffs provides a formalised mathematical approach to shape representation, focused on the needs of computational geometric modeling. For example, this figure given in Stouffs' thesis Figure 2.15, explains how to get from  $U_{33}$  to  $U_{23}$ , by using a Boolean operation.



**Figure 2.15:** Arrow from U33 to U23 showing a process from The Algebra of Shapes. Source: Stouffs (1994).

However, in this research, the mathematical operation is not explicit and not the focus. Instead of outlining the background process for U<sub>23</sub>, only the end result is defined in this research, just the geometry of U<sub>23</sub>.



**Figure 2.16:** Arrow from U33 to U23 showing Stiny's geometry dimensions.

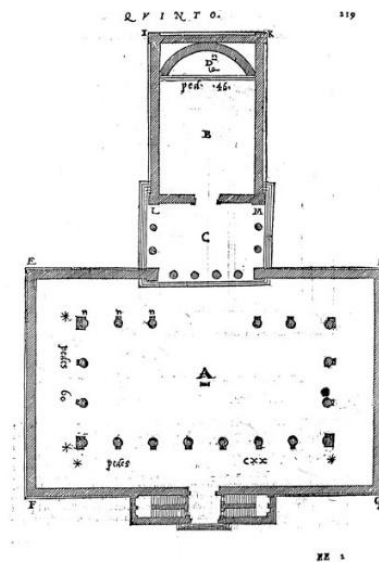
### 2.3.1 GRAPHIC INFORMATION ATTRIBUTES

From high level information, graphic representation can be refined to capture more data about the city and communicate more detailed information. Since early in history design representation has come in many forms, including engravings of maps on stone, such as ancient cartography, man's attempt to represent his world (Muhly, 1978) to building physical scale models such as Antoni Gaudi's La Sagrada Familia to analyse and communicate his design (Giralt-Miracle, 2015). Representation has become a core of many professions that involve the

real-world. The emergence of great civilizations has seen the evolution of graphics as a methodology that can be traced etched from ancient clay tablets to modern CAD (Barr & Juricic, 1994).

Points, lines, and planes has had a long history in the communication of design on plans, sections, and elevations. Using geometric elements, shapes and theories have solved difficult problems in building design. Graphic application and graphic thinking aid design development, design cognition and communication.

Since antiquity, shapes play a central role in communication of space and time. Andrea Palladio's representation of the ancient ruins of Basilica de Fano in 1556 was a graphical translation of a piece of architecture long gone. Enshrined in words and described in detail within the ancient texts of *De Architectura*, Basilica de Fano by Marcus Vitruvius Pollio in Figure 2.17, can be conveyed when words are translated into shapes that give meaning to how the world around us is understood. To articulate some design detail, the labels on the shapes provide more information relating to scale, direction, and orientation.



**Figure 2.17:** Basilica de Fano based on *De Architectura* by Vitruvius. Source: Palladio (1556).

As such, to explore the use of shapes in the previous sub-section this research examines further the use of Stiny's graphics theory on shape. Stiny explores the use of labels and weights to further manipulate and modify the algebras of shapes. See Figure 2.18.

As an expressive device, the points, lines, and planes method well and truly represent geometric concepts but are not easily relatable with material and physical objects. Hence the use of geometric elements and shapes can be combined with other symbols and used as labels to enable better expressions.

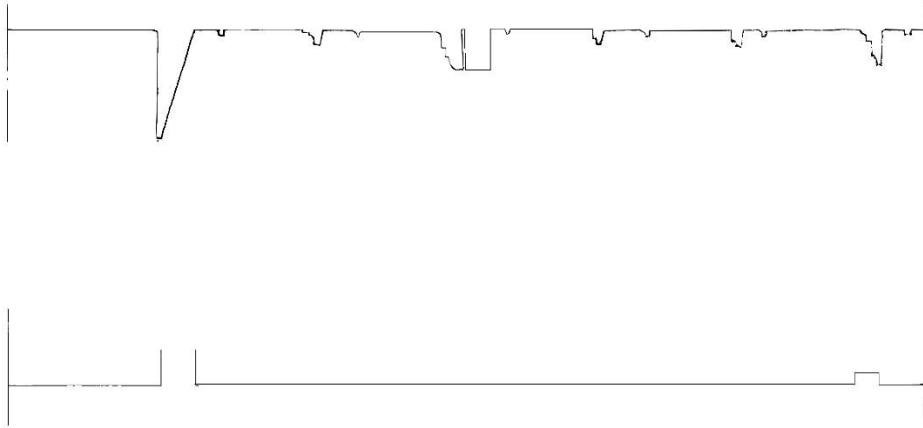
The use of alphabets is an example of label combined with shapes. According to Stiny labels can either classify basic elements or parts of shapes and can also introduce another layer of semantics. In the same token the use of weights can also introduce a system of meaning. Points can be enlarged to indicate meaning; lines can have varied thicknesses and planes can have varied tones.



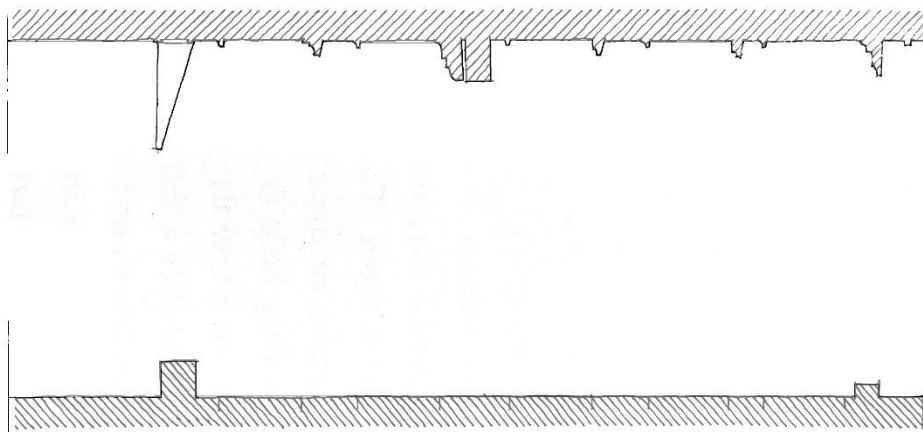
**Figure 2.18:** Graphical Weights. Source: Stiny (1980).

For the purpose of representing information relating to space and time, labels and weights can be employed to communicate orientation, speed, direction, and other spatial concepts.

As example, observe this geometric shape made of lines on a surface with the algebraic expression of  $U_{12}$ . This shape can represent anything from a line graph, a small object such as the shape of a flat piece of steel with a jagged edge to a larger object like a fence or a wall.



Using graphical attributes as cues can improve understanding of the lines and the information they're trying to communicate.



The use of shading such as this, to add *Intensity in Space*,



**Figure 2.19:** Allan B Jacob's deconstructed street in Great Streets

in this imagery can help the viewer understand there is a distinction between the space in between the original geometric shapes maintained as white and the spaces above and below which had been treated as darker. If it represents a large object, such as a fence, the object is

brought forward to the foreground and the spaces above and below further to the background. If vice versa in which the shaded top and bottom are the important objects brought to the foreground, the white space in the middle is simply an open space beyond. The shading using the hatching technique provided more spatial information relating to depth, and the relationship between the top and bottom geometric shapes, that they are positioned at the same distance to the viewer.

To improve the viewer's understanding, more attributes can be employed to add more meaning to geometric shapes.

The geometric shapes as well can be labelled, and lines given weight.

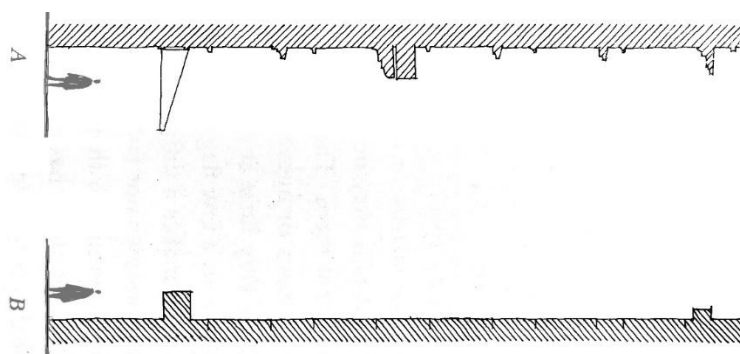


Label, as *Orientation in Space*:

Weight, as *Intensity in Space*:

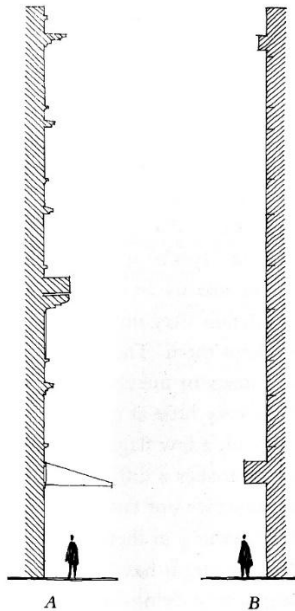
In the following version, the added shapes of persons are used as labels to communicate orientation and scale and improve spatial understanding.

The line under the persons had been made thicker or given more weight to communicate intensity. As such the viewer is in a better position to understand the meaning of the original geometric shapes.



**Figure 2.20:** Rotated street in Great Streets. Source: Jacobs (1993).

The geometric shapes can be understood better. The viewer can observe orientation, that the original geometric shapes should be rotated anticlockwise, and the thicker line would make more represent the solid ground.



*Building wall sections of two buildings on Via Cola di Rienzo, Rome; the more complex facade, A, offers more surfaces, more opportunities for shadow and light changes than does facade B*

**Figure 2.21:** Street in *Great Streets*. Source: Jacobs (1993).

We investigated earlier about the relationship between space and time. Adding nuance to data can allow this investigation to explore a way to communicate spatio-temporal information.

We examine how Newton's three laws of motion that rely on inertia, acceleration, and opposite forces can be represented using graphical attributes to communication concepts relating to space and time. The first law, Inertia relates to the question whether the object is in a state of rest or in a state of *motion*. Is it static or dynamic? The second law, Acceleration relates to information on *velocity*, or direction with speed. The third law, Opposite *forces* is the presence of action and reaction which would look like opposing movement directions such as up and down or push and pull.

This investigation now examines and presents the critical data that can logically represent these three laws of *motion*, *velocity*, and *force*. For the purpose of this research, it can be observed that if data of *direction* and *speed* can be graphically represented, these can be used to sufficiently satisfy the three laws of motion.

First law, motion:

1- *Speed* satisfies the answer as to whether the object is in a state of rest or in motion.

With the presence of speed, it can be claimed that an object is not at rest or static.

Second law, velocity:

2- *Speed* with *direction* can also satisfy understanding of acceleration or the object's rate of change of speed and direction, or velocity.







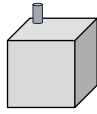
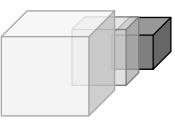
Third law, force:

3- *Direction* with motion, a state in which the object has *speed*, can satisfy understanding of the presence of opposite forces.

Hence, both direction and speed are two critical data that must be graphically represented to communicate concepts of space and time. To enable better expressions that can be illustrated using geometric elements and that are relatable to space and time, graphical attributes can be employed to improve representations of direction and speed. Graphical Labels can be used to communicate orientation as it relates to space and *direction* as it relates to time.

Graphical Weights can be used to communicate intensity as it relates to space and *speed* as it relates to time. Adding these to the understanding of the geometric shapes and their dimensions explored earlier this table illustrates how labels and weights can be applied to geometric shapes. This can be employed to convey information on direction and speed, to improve communication of concepts of space and time.

**Table 2.2: Graphic Information Attributes**

<u>DIMENSION</u>	<u>SHAPE</u>	<u>LABEL</u>	<u>WEIGHT</u>	<u>GRAPHIC VARIATION</u>
		<p><i>orientation</i></p> <p>(relates to space)</p> <p>or</p> <p><i>direction</i></p> <p>(relates to time)</p>	<p><i>intensity</i></p> <p>(relates to space)</p> <p>or</p> <p><i>speed</i></p> <p>(relates to time)</p>	
0D	Point			Point size, point colour, marking
1D	Line			Line colour, line thickness, line type
2D	Plane			Planar colour, hatch type
3D	Solid			Solid colour, transparency

We can observe from the table above how graphic attribution can be employed to communicate space and time concepts. The level of information in geometric shapes and their capability for more content and more complex semantic algebra can be increased to be able to communicate critical space and time details.

To iterate Subsection 2.4.1, communication of movement information is harder to capture and are featured minimally on conventional two-dimensional (2D) drawing of plan, section, elevation, and perspective drawing.

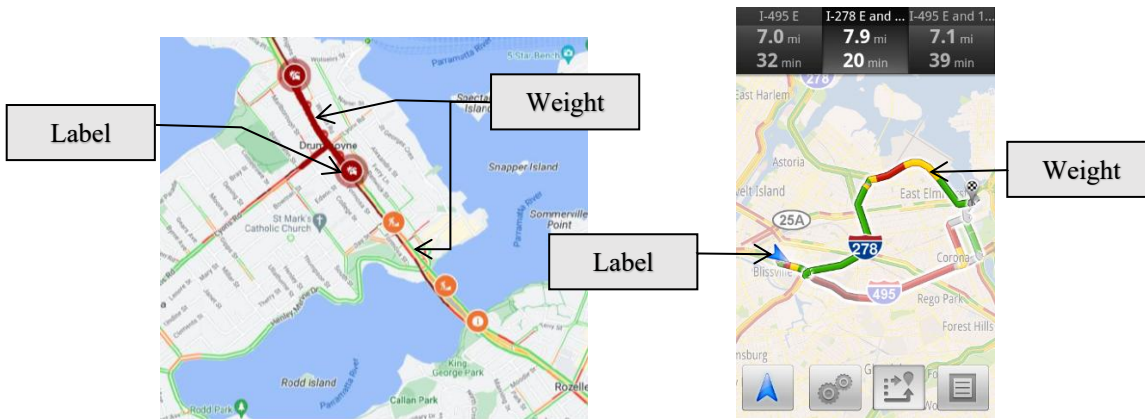
Design presented contextually in relation to the physical world we live is of great importance in the plan, section, elevation communication method. Details relating to location, arrangement of spatial elements, articulation of features, construction information, scale, space and formal relationships in context with detailed measurements are the main scope of the plan section elevation. Minimal information however relates to movement. Labels such as arrows are used for a variety of parts that need to convey direction. Arrows feature on a set of stairs on plans to indicate an up or down direction. In construction drawings this is also accompanied by number labels starting with 1 to indicate the bottom first step. Arrows on empty space to indicate an entrance, arrows on a sloped roof to indicate direction of fall, and arrows on panels to indicate a sliding door, as such arrows on the road indicate direction of movement that takes place on the road.

Although conventionally graphics on plan section elevation contains minimal movement information, we can observe the efficient use of graphics to increase movement information on current 2D computer applications and mobile devices.

An example is live traffic information on 2D maps in Figure 2.22, provided by Google Maps. The use of weights, labels and variation allows better understanding of movement of vehicles along the bridge. We can observe the change from green, orange, red to dark red

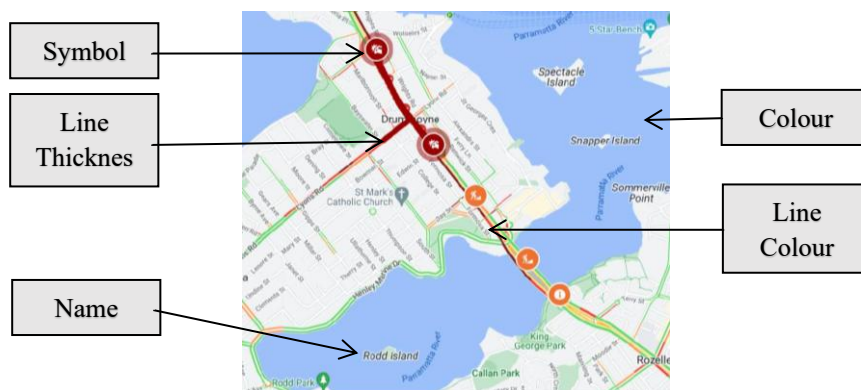
indicating intensity (space) and slow speed (time) for dark red. The use of variation and labels improve how we understand traffic conditions.

Basic analysis will show:



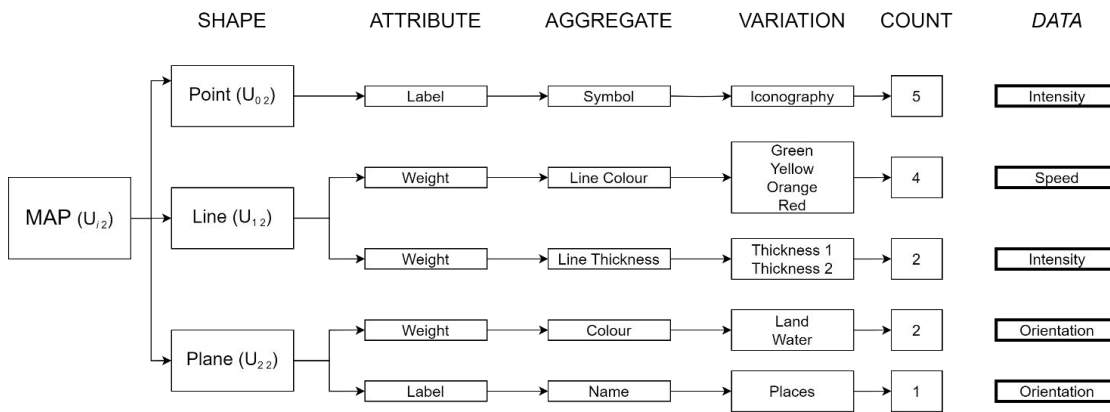
**Figure 2.22:** Google maps showing the use of labels and weights in visual information. Source: Google Map (2024)

However, a more detailed analysis of the map at the *Variation level* can reveal qualities that can be measured using Shape and Graphic Attribution



**Figure 2.21:** Google map showing the use of symbols and colours. Source: Google Map (2024)

Based on the Graphic Attribution table, *intensity, speed, and orientation* data can be decoded from the map.



**Figure 2.24:** Sample counting for the geometric elements of Map.

According to this analysis, Line Shape communicates both *Speed* as it relates to time, and *Intensity* as it relates to space. The Plane Shape communicates *Orientation*, i.e. how the land is located in relation to the waters. Point Shape communicates intensity at certain locations signified by the icon labels.

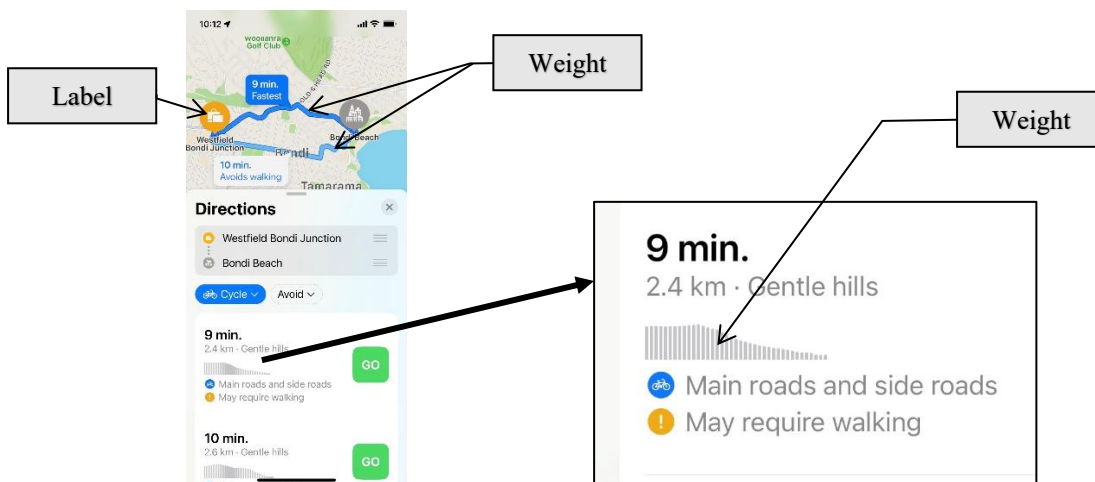
Using this analysis, it can also be concluded that *Direction* information is lacking. Hence, when looking at the map it is unclear as to which direction has traffic delays. However, Google maps convey enough information relating to real time conditions to help the audience navigate routes and make informed travel decisions.

Another example below of Weight and the use of line types. *Speed* is not the only data as it relates to time this attribution can represent but also an *event* in time. The dotted line indicates a future alignment. It can be observed that the use of line types, labels and their definition listed on a legend provides information relating to the road, communicating a *distance* in time.



**Figure 2.25:** Citylink Cycleway Trial. Source: Brisbane City (2024).

Another helpful example below of using graphical attributes with shapes to communicate a space and time concept can be observed in the Maps mobile application. Communicating road conditions such as slopes in relation to space and time can be observed in the map with a *distance* of 2.4 km and *time* of 9 min. Read from left to right, the road will start at a high point with gentle hills and slope down to the destination from halfway through. The Weight used on the shape conveys segments of the road, and communicates as to where the gentle hills or how the slope occurs.



**Figure 2.26:** Google map directions showing the use of labels and weights. Source: Google Map (2024)

In a similar way that time and space information can be conveyed on 2D maps, the image below of a head-up display (HUD) using augmented reality from Stradvision demonstrates the

use of shapes and graphical attributes of Label and Weight on 3D space for better understanding.



**Figure 2.27:** AR HUD System. Source: HTF Market Intelligence (2024).

To summarise these assumptions, space and movement information are a critical factor to improving representation techniques in current practice. As well, communication of space and time are interdependent. It can be observed that representation of space with time can improve the way we understand precise concepts relating to movement. The use of labels, weights and variation provides an opportunity to improve the way meaningful space and movement information can be conveyed.

## 2.4 QUANTIFYING GRAPHICAL DATA

As the graphics processing discussed in the previous section is essential for understanding, analysing graphical information and quantifying data represents a critical next step in enhancing analysis at a granular level.

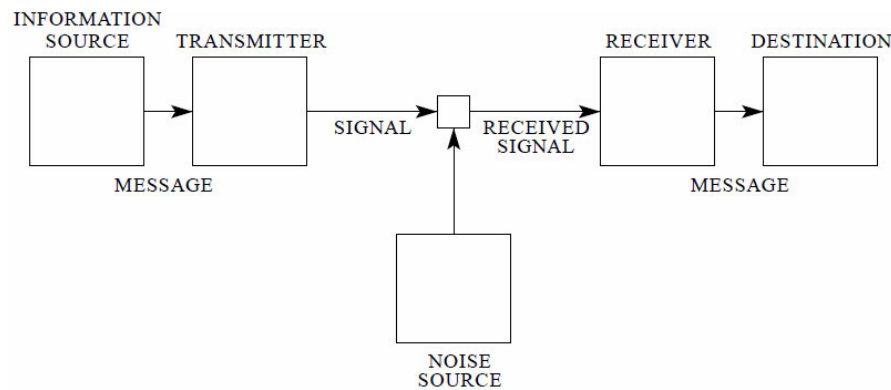
Quantification and computability of design aesthetics is an ongoing topic of research investigation. A number of works have been considered hallmarks in this space. The classical work of George David Birkhoff, a distinguished mathematician, on Aesthetic Measure concerns the formalisation of aesthetics (Birkhoff, 1933). This is the first quantitative theory and have been considered to have influenced today's computational aesthetics. Birkhoff's

theory on aesthetics proposed a definition for the aesthetic measure of an art object. According to Birkhoff, aesthetic experience consists of three stages: "... (1) a preliminary effort of attention, which is necessary for the act of perception, and which increases in proportion to what we shall call the complexity C of the object; (2) the feeling of value or aesthetic measure (M) which rewards this effort; and finally (3) a realisation that the object is characterised by a certain harmony, symmetry, or order (O), more or less concealed, which seems necessary to aesthetic effect" (Birkhoff, 1933). Birkhoff proposed a simple formula for aesthetic measurement:  $M = \frac{Order}{Complexity}$ . The specific definitions of O for order in the work to be examined and C for complexity depended on the type of the analysed object.

This broke new ground for research on quantifying aesthetics and continues to influence further research in the field. The Complexity in Birkhoff's theory is the component that addresses the quantification of aesthetics. This process generally requires the decomposition of the work of art under review and involve the process of examining specific features and their descriptions for measuring and assigning values. Birkhoff's measure used visual references by counting polygon, edges and vertices.

Various theorists in the last century have used Birkhoff's formula as starting point to integrate other ideas from psychology, computational linguistics and mathematics (Hoenig, 2005; Rigau, Feixas & Sbert, 2007). Several researchers have contributed to the complexity measure, integrating *information aesthetics*, and *generative aesthetics* among others, for a new approach to the issue of complexity. It became a movement in the 1960s and works by Max Bense and Claude Shannon who played pivotal roles, were significant in the movement (Greenfield, 2005). Shannon's Information Theory has been foundational in processing communication. His work revolutionised how information can be measured, quantified and described for the purpose of filtering, delivering and receiving communication as illustrated in Figure2.26. Although Shannon's Information Theory measures information in terms of

quantities and also uses a computational approach with a mathematical framework, it operates with binary digits or bits, which are 0 and 1.



**Figure 2.28.** Shannon’s schematic diagram of a communication system.

Based on Stiny’s algebraic expression for information, Shannon’s binary digit of 0 or 1 can be expressed as  $U_0$  in which the information it relates to is operating in the lowest dimension. As this research seeks to process information that includes higher dimensions, from  $U_0$  to  $U_3$ , it will explore an alternative system.

In recent research the issue of the complexity measure is still a hot topic of interest and a subject of exploration. Computational Aesthetics, a subfield in the context of computer science, exploits computational methods to measure and quantify aesthetics for evaluating beauty in works of art (Hoenig, 2005; Rigau, Feixas & Sbert, 2007; Bo, Yu & Zhang, 2018). Research by Bo, Yu & Zhang in 2018, for example, carried out user surveys to develop a matrix for appeal ratings which provided the basis for feature selection in a work of art. The criteria included a number of parameters such as: composition, imaging features of colour, luminance and exposure, edges in terms of spatial distribution, sharpness, and contents. Regions are also segmented before the aesthetic assessment in order to focus on areas for evaluation rather than assessing the entire image’s aesthetics (Bo, Yu & Zhang, 2018).

While the list of criteria demonstrated potential, it also revealed some shortcomings. A noteworthy distinction made by Hoenig offered a valuable insight for identifying a more

tailored approach. Hoenig asserted that to grasp aesthetic problems within a broader context, one must differentiate between works of design and works of art. The latter, unlike the former, lack functional requirements, thus permitting unconstrained aesthetic possibilities. In this regard, there are no determined objective demands for their aesthetics (Hoenig, 2005). This distinction underscores the complexity inherent in developing aesthetic criteria for evaluating urban design artefacts. A tailored aesthetic approach must consider both functional and visual parameters.

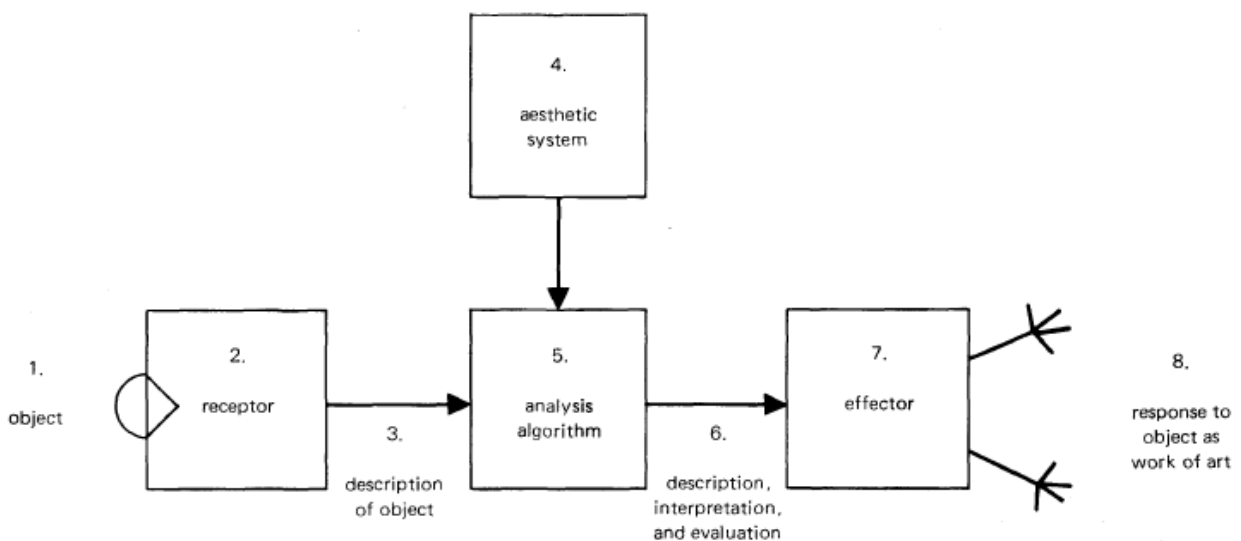
The other significant issue regarding complexity is the approach to developing metrics that seek to align human perception with the automation of the quantification process (Hoenig, 2005). This approach is increasingly relevant, as Aesthetic Measure and computational aesthetics intersect with artificial intelligence. These seek to address challenges related to how computers can effectively simulate the human's perception in the decision-making process of selecting and evaluating aesthetic expressions.

Considering these factors, it became desirable to eliminate the requirement of aligning human perception with the evaluation process for the purpose of simplification and objectivity. This can be done by basing a list of criteria for feature selection on other logical accounts. Consequently, this research adopted an alternative approach by employing the use of urban objects to decompose the visualisation of artefacts, thereby limiting human involvement in decision-making. While this process was previously identified as a potential weakness in the system, an optimal approach to address this is by allocating the task to a computer program, thereby rectifying this weakness.

## 2.5 ALGORITHMIC AESTHETICS

George Stiny and James Gips's Algorithmic Aesthetics describes *aesthetics* as concerned with questions about how existing works of art can be described, interpreted, and evaluated and with questions about how new works of art can be created. The critical factors of description, interpretation and evaluation of an existing work of art is called *criticism*. Criticism is also taken to include the efforts of any observer to understand and evaluate a work of art, whether or not the observer considers himself a professional critic (Stiny & Gips, 1978). The unique aspect of this process for describing, interpreting and evaluating is that it makes extensive use of algorithms.

The argument for an algorithmic process is that algorithmic representations require an explicit awareness of underlying assumptions and details that may remain hidden, or in the case of urban design may remain ambiguous and disassociated, using less rigorous methods. Further, completed algorithmic representations of ideas provide a test of their consistency and soundness and a means of identifying their consequences, as completely specified algorithms can be run on a computer (Stiny & Gips, 1978).



**Figure 2.29:** Postulated Structure for Criticism Algorithm. Source: Stiny & Gips (1978).

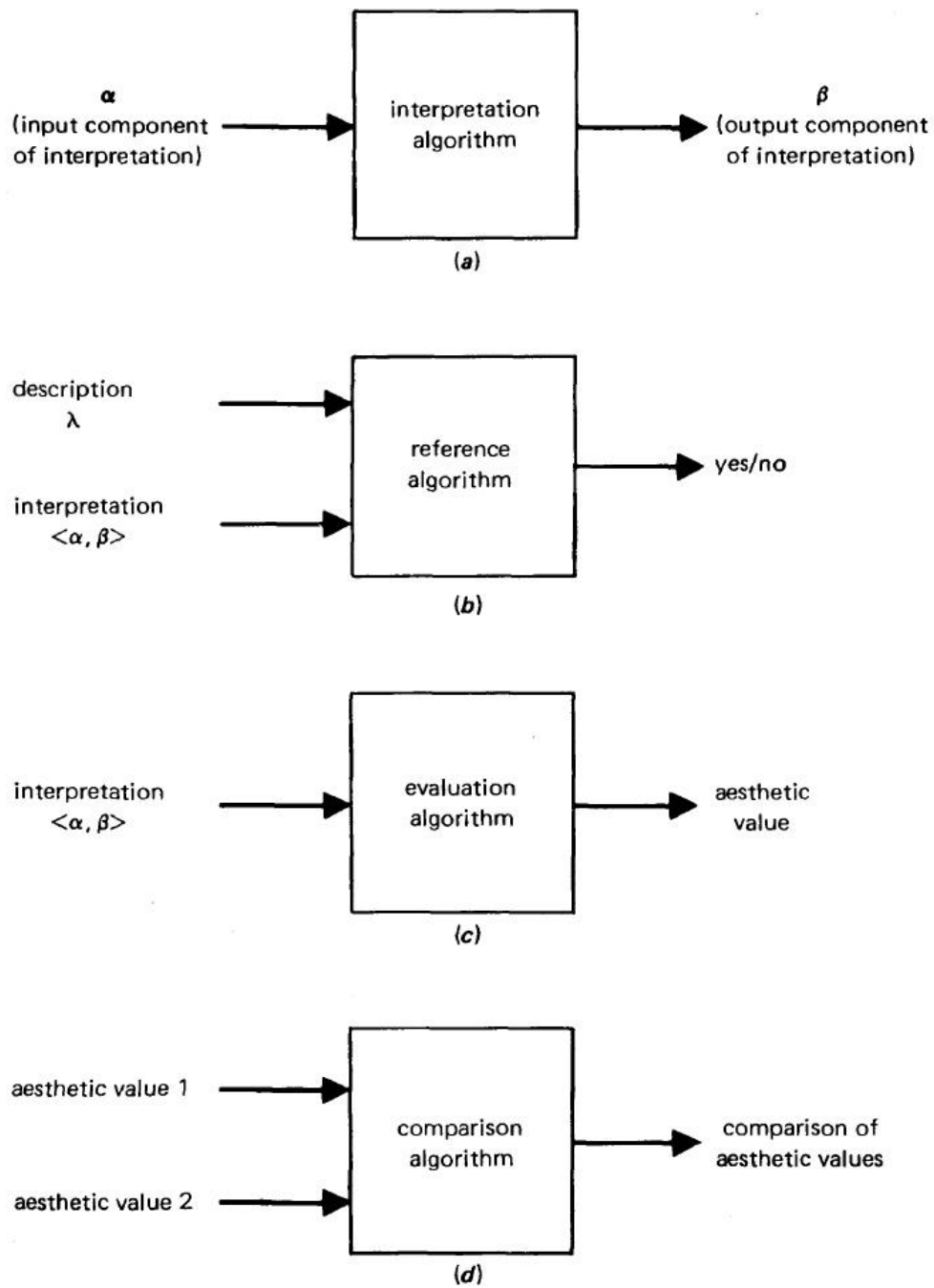
As seen in the above table, the structure for a criticism process is devised as an algorithm in which description, interpretation and evaluation are well defined and play an important role in the process. The notion of *object* as a possible work of art is used in its widest possible sense to include, for example, musical or theatrical performances as well as novels and other works (Stiny and Gips, 1978). This provides an opportunity for this research to model an investigation using this framework. Algorithmic Aesthetics offers a more viable system that can process higher-dimensional elements. It can process information from  $U_0$  to  $U_3$ , including Shannon's binary framework.

Critical descriptions, critical interpretations and critical evaluations in this schema are constructed as seen in this table, to formulate and investigate issues in aesthetics and are formed as components to the algorithm.

Second, to customise the schema for this research:

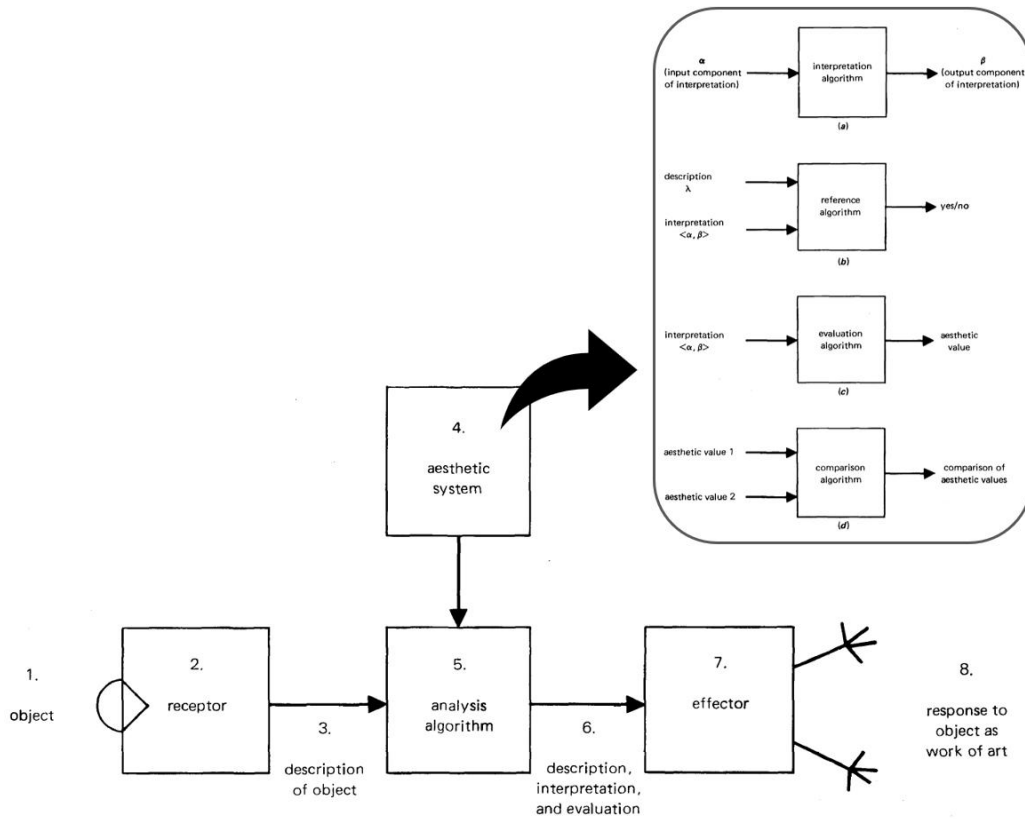
The components of the *Postulated Structure* above are considered *aesthetic system* as seen above in Table ## is of great significance.

This black box contains an algorithm that has the structure as illustrated in Table ## which defines the four components of the 4. *Aesthetic System*.



**Figure 2.30:** Aesthetics System. Source: Stiny & Gips (1978).

To describe how they fit together is illustrated in figure 2.26. In this illustration, the system is now defined to include the aesthetic components in the postulated structure of the algorithm schema.



**Figure 2.31:** Algorithmic Aesthetics. Source: Stiny & Gips (1978).

## 2.6 CONCLUSION

This review investigated relevant literature that highlight the challenges in visual communication used in urban design projects and highlights work that has been done to address the gaps discussed. The review also explores existing theories on visual graphics and techniques that are relevant to this research.



# Chapter 3: Methodology

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This chapter outlines the research methodology, including the experimental procedures and calibration processes. Section 3.1 introduces the research approach to visual communication analysis. Section 3.2 details the research schema based on Algorithmic Aesthetics, outlining the components that relate to the research workflow of analysis and evaluation. In Section 3.3, the Evaluation method is explained, highlighting the use of a statistical data analysis schema that facilitates the production of evidence-based artefact evaluation results.

## 3.1 INTRODUCTION

The literature review presented in Chapter 2 reveals significant limitations in existing research on the evaluation of visual communication artefacts, particularly regarding their efficacy and relevance to stakeholders in urban design projects. Additionally, it highlights the limited available literature addressing the precise impact of both analogue and digital communication artefacts within this field. These gaps present a valuable opportunity to investigate ways to measure visual communication artefacts' performance and stakeholder relevancy.

The research methodology is developed as an algorithmic schema that operates to analyse artefacts and evaluate their relevance and efficacy that satisfy stakeholders' information needs. This system integrates three key processes. The first process involves formalising and rationalising aesthetics, which entails decomposing the artefact and examining specific features and descriptions based on predefined visual metrics to identify quantifiable data. This approach

facilitates the formal identification of visual data, making it suitable for quantification and measurement, .

The second key process is the discretisation and value calculation pertaining to the quantifiable data collected. This process incorporates computations for statistical data analysis that produces the percentage value to reflect the amount of information that is contained in the artefact. It exploits a high-resolution view of graphical information contained in communication artefacts.

The third process evaluates the data against a predefined set of stakeholders' information requirements. This process also includes computations to calculate the data relevancy value. The result of which determines the artefact's score reflecting the percentage of data value or data failure in reference to the stakeholder's information requirement. Furthermore, it establishes the artefact's categorical ranking as either acceptable or inappropriate based on its alignment with stakeholder's needs.

This algorithmic system, developed for measuring and quantifying aesthetics in visual communication artefacts, as well as evaluating their relevancy, serves as a prototype. While some aspects of the system require manual input, calculations are automated. Additionally, the system is designed with built-in capabilities for calibrating various components to refine the analysis and evaluation processes for user preference.

## 3.2 ALGORITHMIC AESTHETICS FRAMEWORK

### 3.2.1 RESEARCH SCHEMA

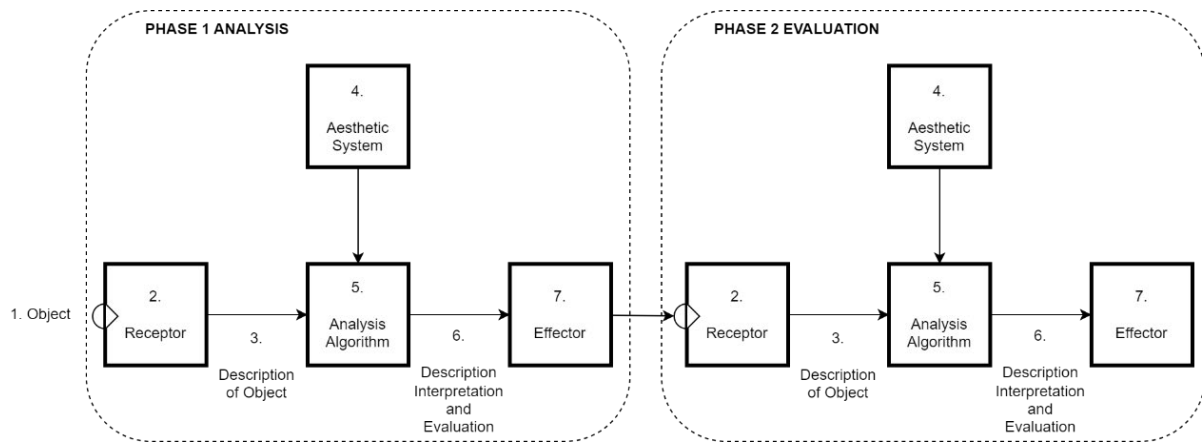
This research uses a formula based on Algorithmic Aesthetics by George Stiny and James Gips shown in Figure 2.29. As shown in the review, *Evaluation Procedure* refers to a systematic formula for a criticism process. Criticism is described to include the efforts of any observer to understand and evaluate a piece of work and distinguish which is better. This process also makes extensive use of algorithms, as Algorithmic Aesthetics is a system with a series of commands, formal definitions and follows a specific flow and order with problem solving operations. As this system is adaptable with a black box of empty containers, these are required to be defined.

Using the Algorithmic Aesthetics framework the research makes formal definitions which consist of assumptions and conventions derived from urban design practice. This process will pin down the contextual requirement of this communication study.

Designed to operate as a value system, this algorithm schema operates as a value system that is used to analyse and evaluate artefacts so that data in communication artefacts are quantified and measurable to produce explicit evaluation results. As such the research framework will consist of two phases. Phase 1 is the analysis of the artefact which will process the information into quantifiable data.

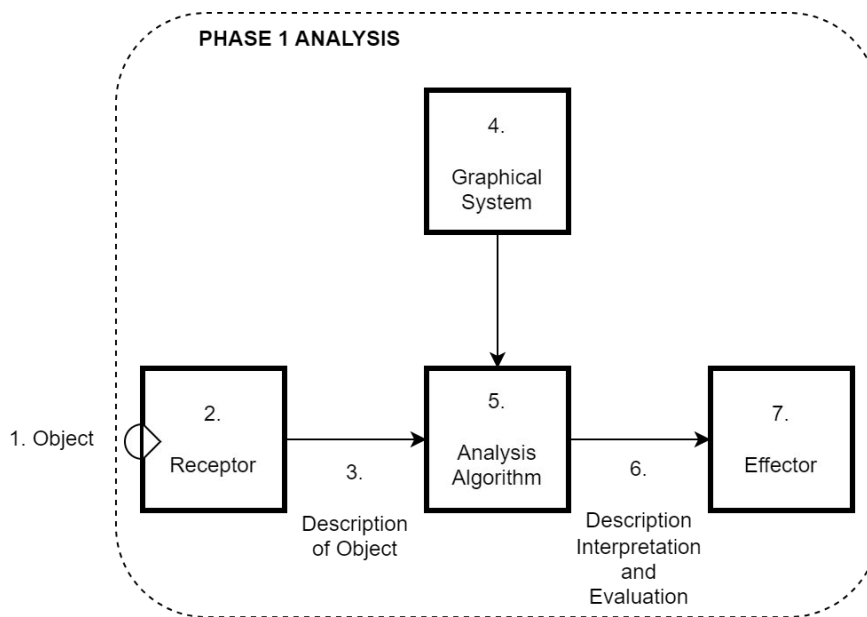
Phase 2 will use the analysis results to evaluate the artefact's performance against stakeholders' communication requirements.

In this Sub-Section, the research flow from Phase 1 to Phase 2 is explained. The research flow is structured based on the Algorithmic Aesthetics framework. As such the research flow is structured:



**Figure 3.1:** Research Flow.

### 3.2.2 PHASE 1 ANALYSIS COMPONENTS



**Figure 3.2:** Phase 1 Analysis Components.

Phase 1 analysis is a computational system focused on information contained in the artefact to measure and quantify data based on urban design theory on path, edge, node, landmark and district. The research analysis components as shown in the diagram above starts

with 1. Object and finishes at 7. Effector based on the Algorithmic Aesthetics explored in the review. Object is the artefact entered into the system. Effector is the data in the artefact that has been measured and given values.

### **3.2.2.1 Object-Artefact**

As defined in Algorithmic Aesthetics explored in the review, *1.Object* can be any piece of work. In this research the piece of work is the communication artefact. This can be in any format, low-tech to high-tech, analogue and digital in which visual graphics is used to communicate urban design.

### **3.2.2.2 Receptor 1**

The receptor in this research are the graphics that we recognise in the artefact. The artefact is examined to identify urban objects used to visualise design and the urban objects are tagged for identification. As such, urban objects are identifiable visual elements such as furniture, road, car, people, building, tree. These objects improve understanding of design information being communicated. Urban objects help create context and improves how we can detect and identify urban elements that define a city context. Urban objects can be at any scale. If the design relates to a large area, objects can be buildings and large objects that depict the picture. If the design relates to small scale projects, objects can be small such as street furniture. This is explained in Sub-Section 3.3.1.1.

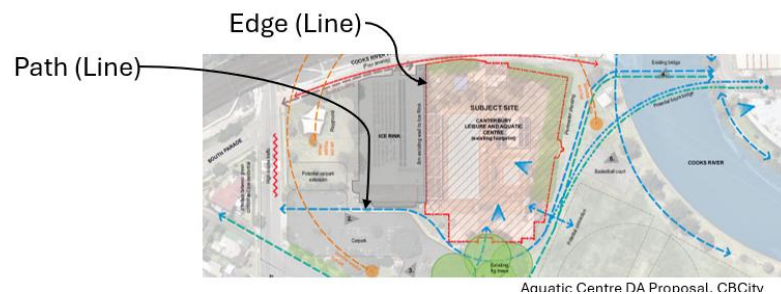
### **3.2.2.3 Description of Object 1**

Urban objects need to be categorised, and their descriptive value identified. As such they are associated with Lynch's urban elements. Urban elements are considered in this research as features by which urban design is recognised and understood as explored in the review on Image of the City. In this research component, knowledge of urban design theory is used as urban objects are categorised for their descriptive value in communicating urban

elements of path, edge, node, landmark and district. This process encodes assumptions and uses knowledge in urban design. This is explained in Sub-Section 3.3.1.2.

### 3.2.2.4 Graphical System 1

This component in the system is the critical analysis and the mapping of graphical data. Lynch's Edge is stripped of its semantics. The idea of an Edge is still maintained as spatial mapping synthesises our understanding of the building on plan represented by a line as a physical limit. Another line might exist that represents the idea of a Path.



**Figure 3.3:** Proposed aquatic centre site. Source: CBCity (2018)

Urban objects and urban elements are discretised to recognise graphical data such as *shape*, *label* and *weight* that are used to convey the urban objects and elements. Graphical mapping is based on Stiny's Algebra of Shapes and Graphical Information Attributes. The process involves itemising points, lines, planes, solids as well as thickness, colours, symbols, line types and such that are used to depict the urban objects and urban elements. This is important to describe, as critical analysis can be done through technological means which will require explicit instructions. The instructions will need to specify and describe urban elements using algebra of shapes and be able to identify them. In this process the artefact is interrogated for its graphical data content. This is explained in Sub-Section 3.3.1.4.

### **3.2.2.5 Analysis Algorithm 1**

Analysis Algorithm is the statistical analysis, the process of recording the graphical quantities of the artefact into data types and are used for computation. It establishes the visibility of the graphical elements and counts the number of occurrences in the artefact. As such, the geometric shapes are quantified in terms of points, lines, planes and solids. As well, attributes such as labels and weights are quantified in terms of symbols, annotations, line types, thickness, colours, hatching and such. This is explained in Sub-Section 3.3.1.3.

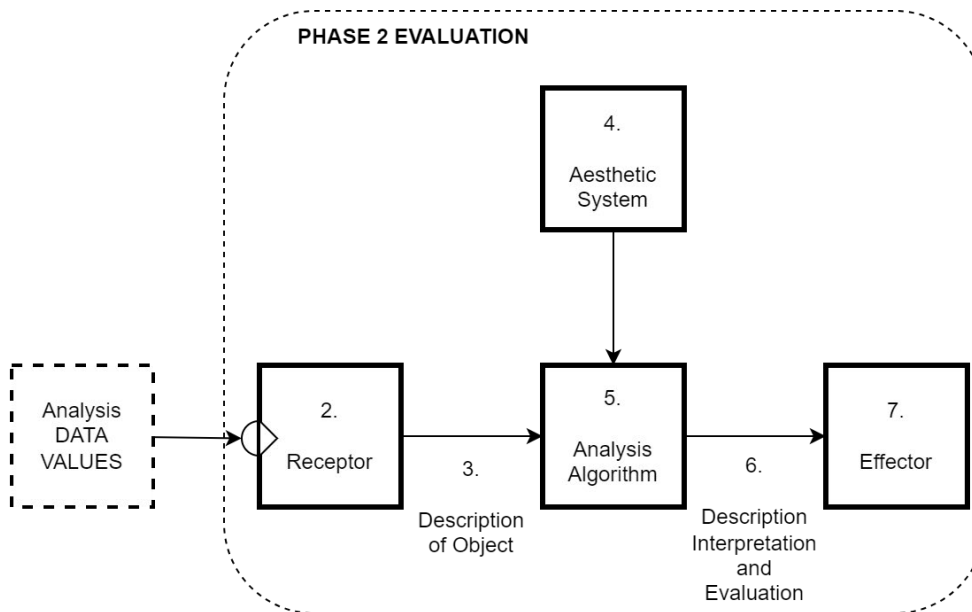
### **3.2.2.6 Description Interpretation and Evaluation 1**

Based on the statistical analysis of the previous step, the quantified data is used to calculate and produce the artefact's data value. The calculation mechanism is based on descriptions and interpretations defined in the system. These are descriptions that dictate the level of importance of each graphical element of shape, label and weight, as well, the level of importance of each point, line, plane and solid that are contained in the artefact. The calculation mechanism is designed as a calibration device, so that the analysis calculation can be fine tuned to meet the system user's requirements. This is explained in Sub-Section 3.3.2.1.

### **3.2.2.7 Effector 1**

Effector, in this research relates to the output of the analysis. It is the result of the statistical analysis and calculations and produces the data values for each urban element conveyed in the artefact, and the total data value of the artefact. This is used as the Input for Phase 2 Evaluation. This is explained in Sub-Section 3.3.2.

### 3.2.3 PHASE 2 EVALUATION COMPONENTS



**Figure 3.4:** Phase 2 Evaluation Components.

#### 3.2.3.1 Object-Data Values

The resulting data values for each urban element in Phase 1 Analysis will be incorporated as Input for Phase 2 Evaluation.

#### 3.2.3.2 Receptor 2

Receptor in this phase is the tabulated list of data requirements by stakeholders to be used for comparison and measured against stakeholders' information requirements. This is explained in Sub-Section 3.3.3.

#### 3.2.3.3 Description of Object 2

The Description of Object relates to the list of requirements specific to individual stakeholders. The data requirements are based on the urban elements of path, edge, node, landmark and district for each stakeholder. This is further explained in Sub-Section 3.3.3.1.

#### **3.2.3.4 Aesthetic System 2**

The Aesthetic System is the framework for identifying stakeholder requirements. The requirements are translated and reduced to a list of urban elements for the explicit description of stakeholders' requirements. In this research this is presented as a calibration mechanism device in order to allow changes to the evaluation matrix and calculation can be fine-tuned to accommodate stakeholders' changing needs and conditions. This is explained in Sub-Section 3.3.3.1.

#### **3.2.3.5 Analysis Algorithm 2**

The Analysis Algorithm is a cross-referencing system. The system cross-references stakeholders' requirements translated as urban elements of path, edge, node, landmark and district against available data on these urban elements identified in Phase 1 Analysis. It also refers to the penalty calculation which relates to the process by which the system assigns penalties against the urban element data if they do not meet the requirements of the stakeholders. It also calculates the percentage of the data available in the artefact that is considered valuable to each stakeholder. This is explained in Sub-Section 3.3.3.2.

#### **3.2.3.6 Description Interpretation and Evaluation 2**

Description Interpretation in Phase 2 relates to the system by which the results are presented. In this research, the evaluation will be presented in values described as a *scoring* and as a *rating*. Penalty calculation which relates to the process by which the system assigns penalties against the urban element data if they do not meet the requirements of the stakeholders. It also calculates the percentage of the data available in the artefact that is considered valuable to each stakeholder. This is explained in Sub-Section 3.3.3.2.

### 3.2.3.7 Effector 2

The Effector is the outcome of the evaluation process. It shows the results of the two-phased evaluation system, explained in Sub-Section 3.3.4. This represents the last component of Phase 2 of the Algorithmic Aesthetics schema and concludes the evaluation process for an artefact in the evaluation system. The result is presented as explicit values for a rating and a scoring of the artefact's efficacy and performance in communicating information to stakeholders. The process quantifies data in communication artefacts and measures this against defined stakeholder requirement metrics to produce explicit evaluation results.

In summary, the diagram in figure 3.6 illustrates the data flow from left to right and how the components link to a system, providing a brief description and the relevant data types associated with each component. This diagram shows how the artefact goes through a sequence of operations through the analysis phase and the evaluation phase. The result produces an explicit scoring and rating of the performance of the artefact for communicative value measured against stakeholders' information requirements.

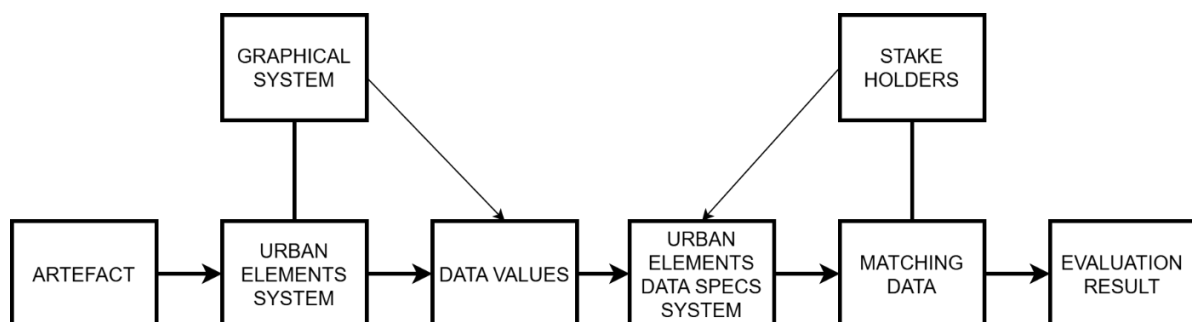


Figure 3.5: Component relationships.

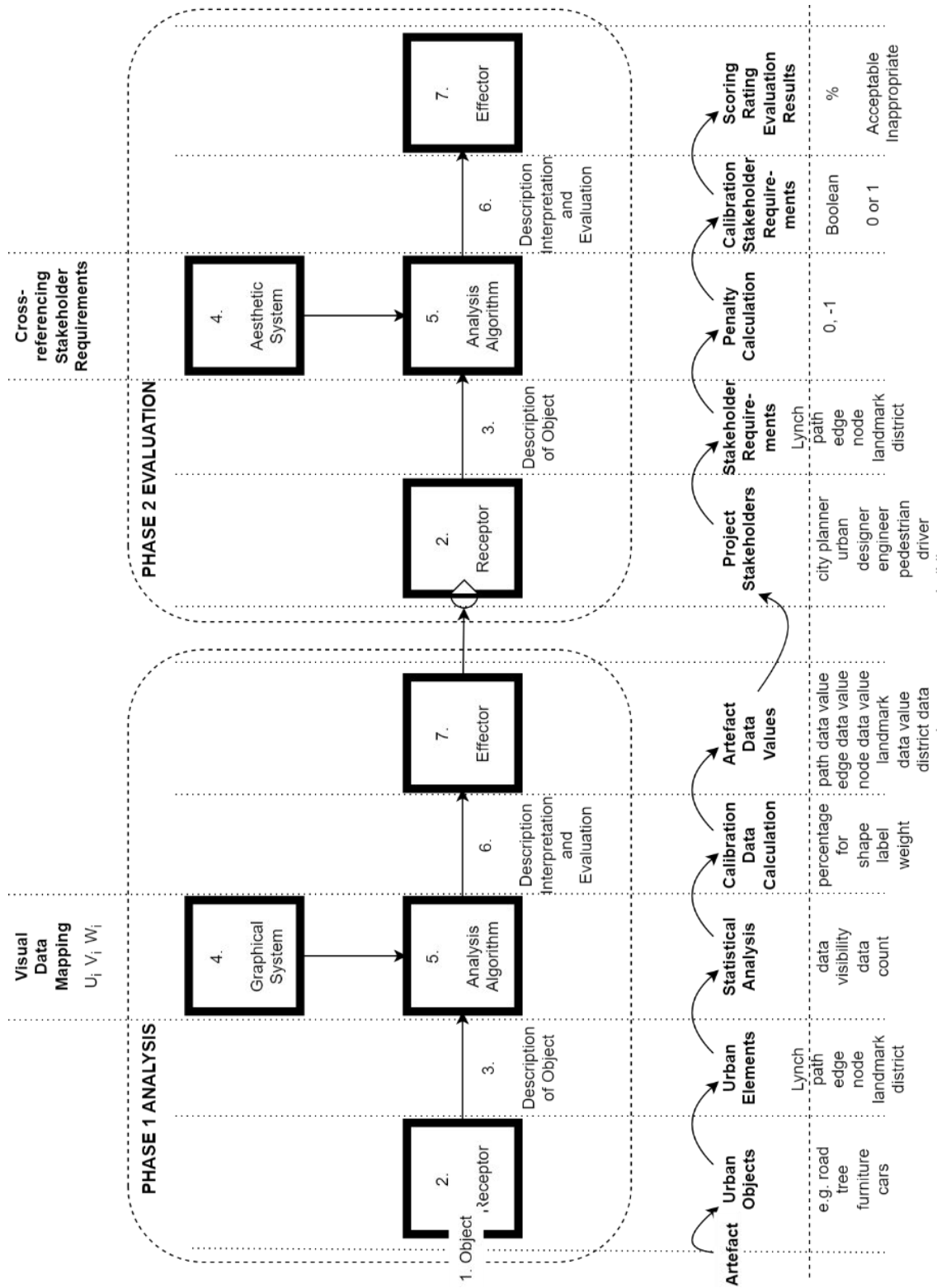
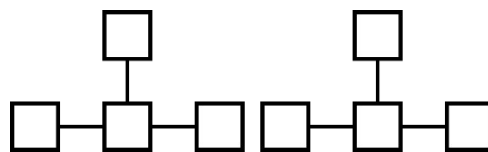


Figure 3.6: Research Flow Details.

### 3.3 THE EVALUATION METHOD

The Evaluation Method is a two-stage validation process using computation which results in the evaluation of artefacts being explicitly determined as either acceptable or inappropriate with a precise percentage value. An example of the final evaluation result, an artefact may produce the result of *66% Acceptable* for an urban designer, *63% Acceptable* for a motorist, but *17% Inappropriate* for a city planner.

The evaluation system has two phases as explained in Sub-Section 3.2. The first phase is the analysis of an artefact which quantifies the data contained in the artefact. The second phase is the evaluation of the artefact using the results from the first phase analysis. The evaluation measures the performance of the data from the analysis against stakeholders' requirements. The following key will be used to identify the relevant component of the system.



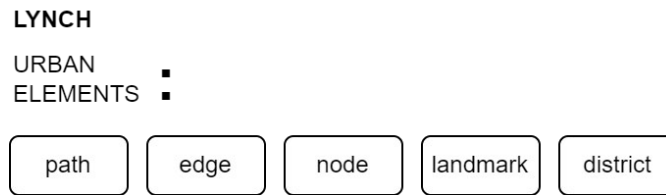
#### 3.3.1 DATA STRUCTURE AND ANALYSIS



The research presents a formulated systematic analysis of communication artefacts that applies urban design conventions. Through this a communication artefact is deciphered using logic originating from urban design theory.

This Sub-Section is the first phase and outlines the analysis at a fine scale using a statistical method for evaluation. The analysis is focused on the communication of urban elements of path, edge, zone, node, landmark and district, and other items called urban objects that are visualised in the artefact. Urban objects can be any of the items depicted in the artefact

to illustrate an urban design. These could be street furniture, building, footpath, vehicles and such. In this research they are associated with urban elements as urban objects support the illustration of the urban elements. It provides context as to how the image is understood in terms of path edge, node, landmark and district. As such urban objects are associated with urban elements.



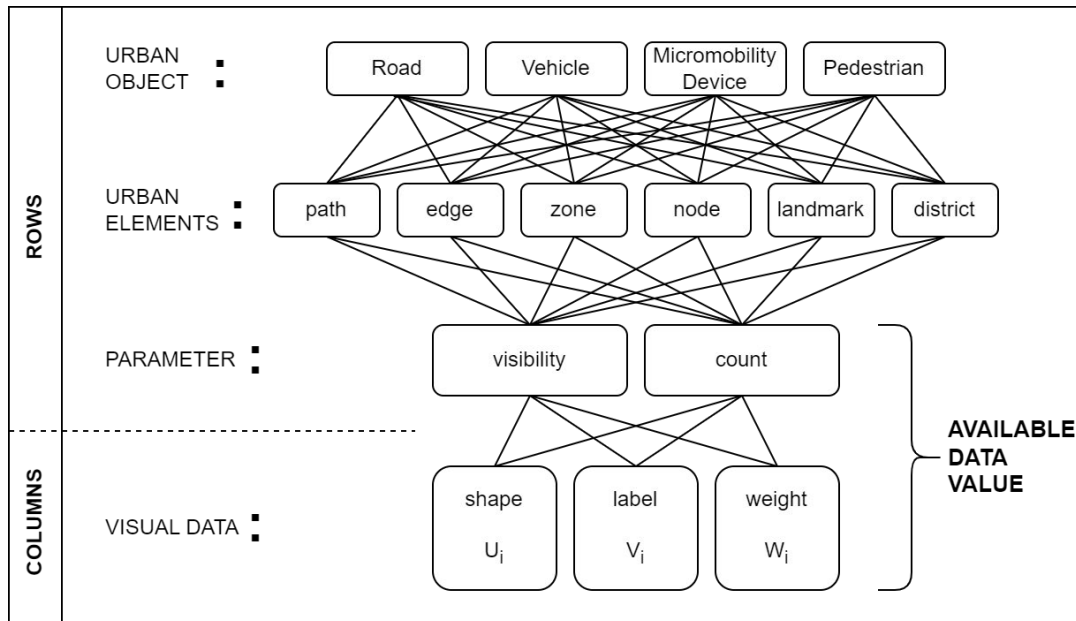
**Figure 3.7:** Data Urban Elements.

The practical mechanism by which the analysis is accomplished is based on the Algebra of Shapes and Graphic Information Attributes by George Stiny explored in the literature review, such as *shape*  $U_i$ , *label*  $V_i$  and *weight*  $W_i$ .



**Figure 3.8:** Data Geometry Algebra.

First, to understand how the data for an artefact and their relationships are defined is explained in the following paragraphs. The table below shows the structure and hierarchy of graphical data in an artefact. Urban objects are identified and associated with urban elements. They go through a process of quantification. Each urban element is quantified in terms of *shape*  $U_i$ , *label*  $V_i$  and *weight*  $W_i$  resulting in numerical values. The total sum will result in the Available Data Value for the artefact.



**Figure 3.9:** Data Structure Table

### 3.3.1.1 Urban Object

As shown in the data structure table, Urban Objects are organised in rows. Urban Objects are graphical representations of objects that populate the visualisation to create a scene. They help articulate the ideas of a design and help viewers recognise Lynch’s urban elements of path, edge, node, landmark and district. One example is street furniture which helps understanding, to illustrate the line close to the furniture can mean the edge of a footpath. Urban objects help create context and improves how we can detect and identify urban elements that define a city context. The furniture when placed between two lines, improves understanding of the space between the two lines, in which one line may represent the edge of a footpath and the other may represent the boundary wall to a building. Each object can be checked against each urban element to identify associations. As example, the road can have path, edge, node and landmark, and so on. The pedestrian depicted in an artefact as well for example can also be associated with path, edge, node and landmark. Buildings may be edge, node, landmark and district. The micromobility device may also be depicted in the artefact to illustrate how movement can occur. Hence it is also considered an urban object as it populates the scene.

### **3.3.1.2 Urban Element**

Urban elements are the identifying visual elements of a city explored in the literature review, path, edge, node, landmark and district. For the purpose of this research, another element is proposed: zone. Although edge, represented by a line, can also communicate a zone, zone provides a unique function distinct from edge. Zone for this research is critical in highlighting the importance of space in the image of a city, that may not be easily illustrated by lines. It embodies a distinct meaning that is spatial and can transcend from 2D to 3D. A tree canopy may be understood on plan view using a ring line, however the space under the canopy may be a critical design objective for use as sitting area, in which case zone means the space under the tree which can be viewed in 2D elevation or in 3D space. As well, in roads, the lines define the space in which the car will travel. Roads that function as mixed traffic, in which the roadway is for a motor vehicle as well as a micromobility device use, may lack lines to define car lanes. The absence of lines that usually define car lanes allow vehicles and micromobility devices to move freely in a slow environment. The design of the roads however requires the spatial qualities of the roads to be conveyed, such as enough space for cars and devices. Zone can be used in this regard. Zone for the car and zone for the micromobility device may be depicted using other visual graphics.

### **3.3.1.3 Parameter**

There are two parameters or numerical factors to measure and record graphical data: Visibility and Count. Visibility indicates whether the data is visible or not. To use numbers instead of words, Yes is represented by 1, and No is represented by 0. Visibility is then either a 1 or 0. Count records the number of times it appears in the artefact.

### 3.3.1.4 Visual Data



As explored in the literature review, according to Stiny in the Algebra of Shapes, shape is a finite set of geometric elements that are defined in dimension index  $i$  in which  $i = 0$  represents points,  $i = 1$  represents lines or curves,  $i = 2$  represents planes and  $i = 3$  represents solids.

#### 3.3.1.4.1 Shape

Therefore,  $U_0$  is a point,  $U_1$  is a line or a curve,  $U_2$  is a plane, and  $U_3$  is a solid or represented with depth. As example, when a line in the artefact represents an edge of the road, this is  $U_1$ . Similarly, if a road path is represented by a line or a curve to indicate how vehicles travel, this is also  $U_1$ . A building may be depicted as a square, in which case the geometric algebra is  $U_2$ . The boundary of a building which is an edge may also be depicted as a line or a curve, in which case the geometric algebra is  $U_1$ . An electric post on plan may be depicted as a dot, in which case the geometric algebra is  $U_0$ .

To record this for statistical analysis, each shape  $U_i$  occurrence is counted, which populates the parameter discussed in 3.2.1.3. Any instance of lines and curves is one  $U_1$ . Any instance of enclosed area is one plane and is  $U_2$ . Any instance of a dot or a spot is one  $U_0$ . Any instance of a solid or a shape that embodies depth is one  $U_3$ .

#### 3.3.1.4.2 Label

The next visual data that needs to be recorded is the occurrence of label  $V_i$ . Label as explored in the literature review on Stiny's graphics theory on shape, label adds information to

the shape  $U_i$  geometry and another layer of semantics. A label is employed to improve representations of orientation, scale and spatial understanding. As such the arrow at the end of a line to indicate road path is considered a label  $V_i$ . The name of the street or words that indicate direction or location is also considered label  $V_i$  for plane. In the literature review, it was also explored that a person or a car on a line can be considered label  $V_i$  to indicate orientation of a line as to which side is up or down. For solid  $U_3$ , or shapes with depth, consider a cube, the pyramid attached to the cube to depict the roof of a house can be considered as label  $V_3$ , to provide meaning as to the orientation of the cube and how it can be understood. Label  $V_i$  adds meaning to shape  $U_i$ . Hence, label  $V_i$  only occurs when shape  $U_i$  exists.

For statistical analysis each label  $V_i$  occurrence is counted to populate the parameter discussed in 3.2.1.3 in relation to its associated shape  $U_i$ . As example, a *path* element depicted in the artefact such as road path represented by a line  $U_1$  with two arrows on each end is counted as having two label  $V_1$  occurrences. This adds more information to the *path* element, a line  $U_1$  geometry for better meaning and understanding.

#### **3.3.1.4.3 Weight**

The last visual data that needs to be searched for and recorded is the weight  $W_i$  geometry. As well, as explored in the literature review, weight  $W_i$  is a graphical information attribute that can be employed to improve understanding of shape  $U_i$  representations and increases spatial information meaning. Weight can be used to add tone, intensity, texture or mood to shape. Point  $U_0$  can be enlarged or coloured which have the geometric algebra of  $W_0$ , to indicate meaning. As do lines or curves, which can have varied thicknesses or line types such as broken or running lines, as well as colour, which have the geometric algebra of  $W_1$ , to add meaning to line or curve  $U_1$ . As well, a plane  $U_2$  can have varied tones, shadows, colours or hatching to

depict intensity, which have the geometric algebra of  $W_2$ . Similarly for solid  $U_3$ , tones, shadows and colours have the geometric algebra of  $W_3$ .

As well, for statistical analysis each weight  $W_i$  occurrence is counted to populate the parameter discussed in 3.2.1.3 in relation to its associated shape  $U_i$ . As example, a road *path* depicted as a line  $U_1$  that is thick for intensity, and coloured red, which may represent a caution or congestion, is counted as having two weight  $W_i$  occurrences. A boundary line that is depicted as a broken line type, may communicate a future proposal which adds meaning to line  $U_1$ . As such, weight  $W_i$  also adds more information to the line  $U_1$  geometry for better meaning and understanding.

As such, label  $V_i$  and weight  $W_i$  are graphical information attributes that add semantic layers to shape  $U_i$  to improve communicative value. Each visual data  $U_i$ ,  $V_i$ , and  $W_i$  occurrences are counted for statistical analysis of the artefact. Each count goes towards a sum value for each urban element to compute the artefact's path, edge, zone, node, landmark and district data values in numeric data. These numeric data values are added up to represent the total amount of data contained in the artefact. The total amount is the Available Data Value of the artefact.

With the use of Algebra of Shapes and Graphical Information Attributes by George Stiny, this is how each 2D and 3D artefact can have comparable visual and meaningful data that computes and calculates urban design information in numerical values based on path, edge, zone, node, landmark and district.

### 3.3.1.5 Data Count Analysis



After review of an artefact in terms of Urban Object explained in Sub-Section 3.2.1.1, Urban Element explained in Sub-Section 3.2.1.2, Parameter explained in Sub-Section 3.2.1.3,

and Visual Data explained in Sub-Section 3.2.1.4, the data is recorded and organised according to the table below.

**Table 3.1: Analysis of data**

urban object	urban element	parameter	shape				label				weight			
			u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3
			point	line/ curve	plane	solid	text/ number/ symbol	line/ curve	plane	solid	point area	thickn ess/ colour	hatch/ colour	hatch/ colour
road	path	visibility count	0 0	1 3	0 0	0 0	1 2	0 0	0 0	0 0	1 2	0 0	0 0	

Table 3.1 shows an example for the calculation for the road, shown on the left of the table, as urban object and the associated urban element of *path* contained in an artefact. As illustrated in the Data Structure table, Urban Objects, Urban Elements and Parameters are organised and listed in rows. Whereas Visual Data of shape, label and weight, as shown at the top of the table, are organised in columns. As shown in the above table, each geometry of shape, label and weight has four columns each. Each column is dedicated to each point  $U_0$ , line/curve  $U_1$ , plane  $U_2$ , and solid  $U_3$  of the shape geometry. Text/number/symbol  $V_0$ , line/curve  $V_1$ , plane  $V_2$ , and solid  $V_3$ , each under a column, are for the label  $V_i$  geometry attribute. Point area/colour  $W_0$ , thickness/colour/type line/curve  $W_1$ , hatch/colour plane  $W_2$ , and hatch/colour solid  $W_3$ , each under a column, are for the weight  $W_i$  geometry attribute.

As shown above under *shape*, the road-path has a *visibility* of 1 under the column of line/curve  $U_1$ , which means Yes. The *count* is showing 3 which indicates there are three lines or curves that are visible in the artefact to illustrate road path.

In addition, the line/curve  $U_1$  geometry has further graphical attributes. The first one is indicated under the label columns. *Visibility* of label under  $V_1$  has 1, which means Yes, and 2 for *count*. This indicates there are two label  $V_1$  occurrences that add meaning to the line/curve  $U_1$  geometry. An example could be that there are two arrows at the end of the line/curve  $U_1$ .

The second graphical attribute to add meaning to the line/curve  $U_1$  geometry is the *weight*  $W_1$ . As shown above, *visibility* of weight under  $W_1$  has 1, which means Yes, and 2 for *count*. This also indicates that there are two *weight*  $W_i$  geometric occurrences that can be detected on the line/curve  $U_1$  geometry. The graphical information of thickness, colour and line type for *weight* adds value and meaning as to how a line/curve  $U_1$  is to be understood.

An example,

the  $U_1$  line/curve, with *visibility* = 1 and *count* = 3 may look like this:

DATA 1



Figure 3.10: Geometry of road-path line graphic.

the  $U_2$  plane, with *visibility* = 1 and *count* = 1 may look like this:

DATA 2



Figure 3.11: Geometry of road-path plane graphic.

Further, if the  $U_1$  line/curve geometry has additional graphical information attributes such as *label* is shown below.

Observe the  $U_1$  line/curve, with *visibility* = 1 (Yes) and *count* = 3 , AND

with a  $V_1$  label of line/curve, with *visibility* = 1 (Yes) and *count* = 2,

the visual representation may look like this:

DATA 3

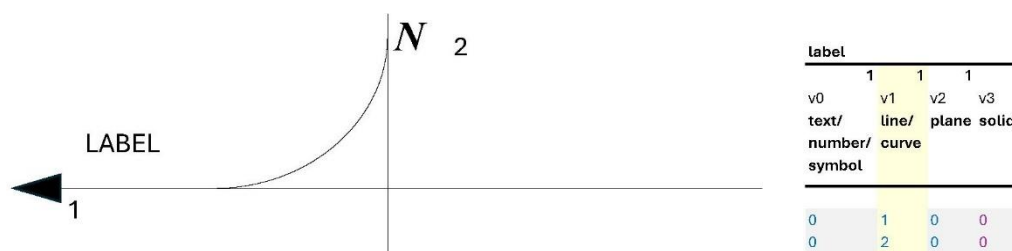


Figure 3.12: Label information of road-path graphic example.

As can be observed, the visual graphic above contains three line/curve  $U_1$  occurrences and two *label*  $V_1$  occurrences. For the line/curve  $U_1$  geometry, there are two graphical information attributes of *label*, one is the arrow, and two is the North symbol.

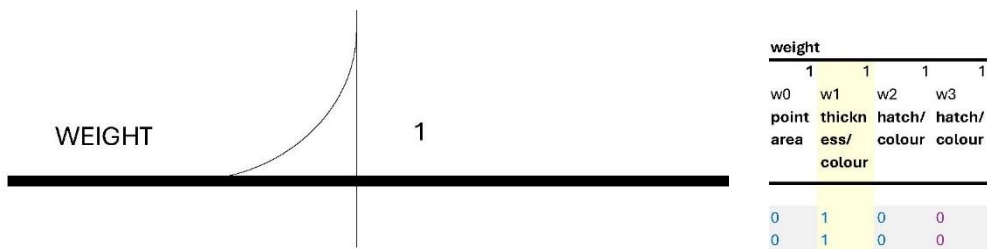
Another expression for DATA 1 above may be showing the graphical information attribute of *weight*  $W_i$  for the  $U_1$  line/curve geometry.

the  $U_1$  line/curve *shape*, with *visibility* = 1 (Yes) and *count* = 3 , AND

with a  $W_1$  *weight*, with *visibility* = 1 (Yes) and *count* = 1,

the visual representation may look like this:

DATA 4



As can be observed, the visual graphic above contains three line/curve  $U_1$  occurrences and one *weight*  $W_1$  occurrence. For the line/curve  $U_1$  geometry, there is one graphical information attributes of *weight* which is thickness.

Similarly, for the  $U_2$  plane, with *visibility* = 1 and *count* = 1 shown in DATA 2, the *weight* information can be exhibited using hatch or colour. In which case, a *visibility* = 1 (Yes) and *count* = 1 for a *weight*  $W_2$  which indicates there is one graphical information attributes of *weight* such as the colour grey contained in the  $U_2$  plane geometry, may look like this:

DATA 4



Figure 3.13: Weight information of road-path graphic.

To show the combined geometry above shown in Data 1 to 4, the numeric data value is shown in Table 3.2.

Table 3.2: Graphic

	shape				label				weight			
	1	1	1	1	1	1	1	1	1	1	1	1
parameter	u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3
	point	line/ curve	plane	solid	text/ number/ symbol	line/ curve	plane	solid	point area	thickn ess/ colour	hatch/ colour	hatch/ colour
visibility	0	1	1	0	0	1	0	0	0	1	1	0
count	0	3	1	0	0	2	0	0	0	1	1	0

When combined, this may look like:

DATA 5

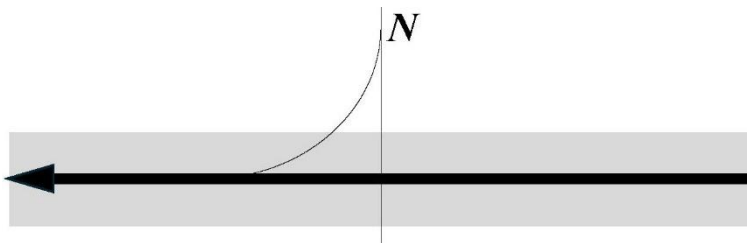


Figure 3.14: Example 1 road-path graphic.

One might understand the graphic as: there is one main road and two minor roads. The main road is going one direction from right to left. A minor road is north-south and intersects with the main road. Another minor road is curved as a short-cut which avoids the intersection.

Similarly, another example in which the graphic recording with the same values might ring true may look like this:

DATA 6

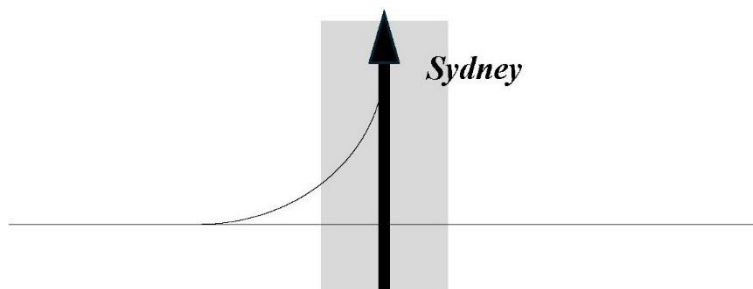


Figure 3.15: Example 1 B road-path graphic.

This graphic also has the same numeric values which is broken down as follows:

$U_1$  line/curve has *visibility* = 1 with a *count* = 3. These are the same items.

$U_2$  plane has *visibility* = 1 with a *count* = 1. This plane is instead rotated vertically

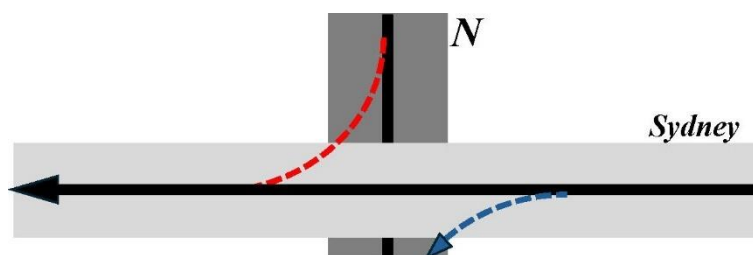
$V_1$  line/curve, *visibility* = 1 with a *count* = 2. These labels are the arrow up and *Sydney*

$W_1$  thickness/colour, *visibility* = 1 with a *count* = 1. This is the vertical line thickness

$W_2$  hatch/colour, *visibility* = 1 with a *count* = 1. This is the same solid colour plane

Another example on applying the same logic and relationships of *shape*, *label* and *weight*, we can observe in the graphic below when the *count* for *shape*, *label* and *weight* are increased.  $U_i$  *shape* geometries can generate a graphic with more meaning and complexity by increasing the *count*.

DATA 7



**Figure 3.16:** Example 2 road-path graphic.

In careful examination in which ***count* has been increased** the graphic will show the following numeric values in Table 3.3.

**Table 3.3: System Data Count**

	shape				label				weight			
	1	1	1	1	1	1	1	1	1	1	1	1
parameter	u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3
	point	line/ curve	plane	solid	text/ number/ symbol	line/ curve	plane	solid	point area	thickn ess/ colour	hatch/ colour	hatch/ colour
visibility	0	1	1	0	0	1	0	0	0	1	1	0
count	0	4	2	0	0	4	0	0	0	7	2	0

This is broken down as follows:

$U_1$  line/curve has *visibility* = 1 with a *count* = 4.

These are two curves and two perpendicular lines.

$U_2$  plane has *visibility* = 1 with a *count* = 2.

These are two perpendicular planes

$V_1$  line/curve, *visibility* = 1 with a *count* = 4.

These *labels* are the two arrows, one north symbol and one *Sydney* annotation.

$W_1$  thickness/colour, *visibility* = 1 with a *count* = 7.

These *weights* relate to the line/curve which has three colours (black, blue, red), 2 thicknesses (the red and blue are the same thickness, the black is thicker), and 2 line types (solid and broken)

$W_2$  hatch/colour, *visibility* = 1 with a *count* = 2.

These *weights* relate to the plane which has 2 colours. One is a solid light grey, and the other one is a solid darker grey.

In this graphic, increasing the *counts* provides a different meaning and changes how we understand the  $V_1$  line/curve and  $U_2$  plane geometries which may bring one to understand:

There are two main roads and two minor roads. One main road is a path that is heading in the direction away from Sydney and the other main road is a path that is north-south. The curved lines are lesser in thickness indicating they're minor roads. As well, both minor roads have added information. The red curved minor road being red may indicate caution, and the blue indicates a different type of condition, such as a future path. The variation in colour for plane also increases the level of information. The darker grey may indicate an underpass road, whilst the lighter grey an overpass.

### 3.3.2 DATA CALCULATION AND CALIBRATION



#### 3.3.2.1 Data Value Distribution

The analysis of the quantified data of *shape*  $U_i$ , *label*  $V_i$  and *weight*  $W_i$  as shown above in Sub-Section 3.2.1, is explained in this Sub-Section.

The process for analysis is to calculate the worth of the data collected. It can be assumed that as visualisations can be subjective, e.g. styles of preferences or requirements, a nuanced approach for calculation will be required.

For example, *shape* might be more important to graphically represent than *label* or *weight*. A more technical style will require points, lines, planes and solids to be more defined. However, in some cases, in which *weight* is more important than *shape*, such as when the artefact is required to be more photorealistic or more vibrant, artefacts can be analysed

accordingly. As well, *label* in some cases may be more important such as in artefacts that depict wayfinding in urban design.

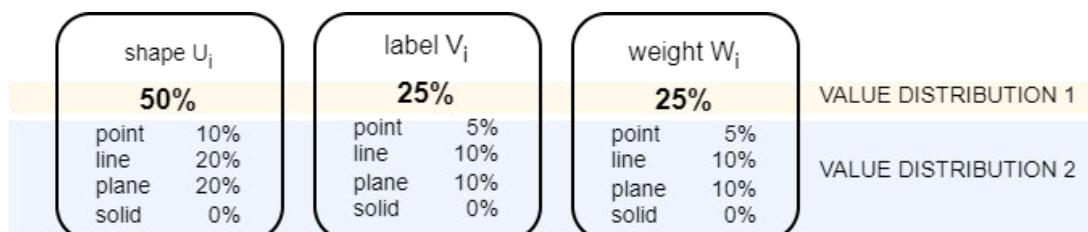
#### Value Distribution 1:

Using 100% as the total value, the value distribution for *shape*, *label* and *weight* needs to be defined. As such, *shape* = 50%, *label* = 25% and *weight* = 25%. Similarly, if *weight* is more important, *shape* = 30%, *label* = 20% and *weight* = 50%. At this level, distribution is called Value Distribution 1.

#### Value Distribution 2:

As well, at a granular level, the values for each *shape*, *label* and *weight* can be further distributed in terms of points, lines/curves, planes and solids, as they can also be valued differently. In some cases, it may be a preference that planes are more important than points, or for a more technical artefact, such as working drawings, points and lines/curves may be more important than planes or solids, and so on. This is the dimension level as points, line/curves, planes and solids relate to dimensions in geometry explored in the literature review. The distribution at this level is called Value Distribution 2.

To illustrate the two levels of value distributions below, Value Distribution 1 defines the distribution at the shape level, then this value is further distributed at the dimensional level which is called Value Distribution 2.



**Figure 3.17:** Value Distribution

### 3.3.2.2 Calculation and Calibration

By using value distribution in the process, the analysis can facilitate a nuanced approach in calculating value to accommodate various conditions and perspectives under which an artefact can be analysed. The calibration table below that reflect these percentages will enable the system to allow these variations in data calculation.

**Table 3.4: Calibration Table 3**

CALIBRATION 3																		
data type	artefact element	shape				50%	label				25%	weight				25%	score	Value Distribution 1
	parameter	u0	u1	u2	u3		v0	v1	v2	v3		w0	w1	w2	w3			Value Distribution 2
boolean (0 or 1)	visibility	0	0	0	0		0	0	0	0		0	0	0	0			
integer (= or > than 0)	count	0	0	0	0		0	0	0	0		0	0	0	0			
percentage	calculation	10%	20%	20%	0%		5%	10%	10%	0%		5%	10%	10%	0%		100%	
result	amount	0	0	0	0		0	0	0	0		0	0	0	0		0	

This table shows the distribution as :  $shape U_i = 50%$

$label V_i = 25%$

$weight W_i = 25%$

To implement this,

The *shape* column is allocated a value of 50%. This is then distributed across as point  $U_0 = 10%$ , line  $U_1 = 20%$ , and plane  $U_2 = 20%$  as described in *calculation* row. The *label* column is allocated 25% value distributed as point  $U_0 = 5%$ , line  $U_1 = 10%$ , and plane  $U_2 = 10%$ . The *weight* column is also allocated 25% with its value distributed as point  $U_0 = 5%$ , line/curve  $U_1 = 10%$ , and plane  $U_2 = 10%$ .

As well, the numbers in the calibration table are colour coded. The **green** colour, which are the percentage values, indicates these numbers can be changed to tweak and calibrate the analysis calculation. The **blue** colour, which are the numbers along the *visibility* and *amount* rows are an Input by the user, either manually or through technological means. When the input values are registered, the system produces the **red** values which are autogenerated.

Hence, Calibration Table 3 is a device in the system used to define the value and to operate the calculations in artefact analyses.

Once Calibration Table 3 is set, the data *count* will be calculated to represent the defined percentages value for each *shape*, *label* and *weight*, and according to the defined percentages value for point, line, plane and solid.

Therefore, the data *count* in Table 3.5 will be calculated as shown below:

**Table 3.5: Data Count for Shape, Label and Weight**

parameter	shape				label				weight			
	u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3
	point	line/ curve	plane	solid	text/ number/ symbol	line/ curve	plane	solid	point area	thickn ess/ colour	hatch/ colour	hatch/ colour
visibility	0	1	1	0	0	1	0	0	0	1	1	0
count	0	4	2	0	0	4	0	0	0	7	2	0
amount	0	0.8	0.4	0	0	0.4	0	0	0	0.7	0.2	0

Observe the *amount* row with the calculated value result in colour red, which is autogenerated. This *amount* represents the percentages in Value Distribution 1 for *shape*, *label* and *weight*, and Value Distribution 2 for point, line/curve, plane and solid, as defined in Calibration Table 3. For now, solid U<sub>3</sub> is in colour purple to indicate is not currently part of the analysis as the artefacts are that of 2D. In the case where an artefact is a 3D visualisation, point U<sub>1</sub> may also be disregarded from the analysis calculation and in colour purple.

As shown in the column under *shape* and U<sub>1</sub> line/curve, the *visibility* is 1 (yes) with a *count* of 4. Based on the given percentages set out in Calibration Table 3, in which U<sub>1</sub> line/curve is at 20%, the result is the *amount* of 0.8, as shown in red.

Visibility	1	Yes=1, No=0 (Boolean)
Count	4	Integer=>0
Calculation	20%	Percentage of Count

Amount	0.8	Result
--------	-----	--------

U<sub>2</sub> plane has a *count* of 2 and valued at 20% gives the result of *amount* = 0.4.

Visibility	1	Yes=1, No=0 (Boolean)
------------	---	-----------------------

Count	2	Integer= >0
-------	---	-------------

Calculation	20%	Percentage of Count
-------------	-----	---------------------

Amount	0.4	Result
--------	-----	--------

Similarly, under *label* and V<sub>1</sub> line/curve, the *visibility* is 1 (yes) with a *count* of 4. As well, based on the given percentages for *label*, V<sub>1</sub> line/curve at 10%, the result is the *amount* of 0.4, as shown in red.

Visibility	1	Yes=1, No=0 (Boolean)
------------	---	-----------------------

Count	4	Integer= >0
-------	---	-------------

Calculation	10%	Percentage of Count
-------------	-----	---------------------

Amount	0.4	Result
--------	-----	--------

*Weight* W<sub>1</sub> thickness/colour which has a *count* of 7 and valued at 10%, results in the *amount* of 0.7.

Visibility	1	Yes=1, No=0 (Boolean)
------------	---	-----------------------

Count	7	Integer= >0
-------	---	-------------

Calculation	10%	Percentage of Count
-------------	-----	---------------------

Amount	0.7	Result
--------	-----	--------

*Weight* W<sub>2</sub> hatch/colour which has a *count* of 2 and valued at 10%, results in the *amount* of 0.2.

Visibility	1	Yes=1, No=0 (Boolean)
Count	2	Integer= >0
Calculation	10%	Percentage of Count
Amount	0.2	Result

This is how graphical data is proposed to be quantified and analysed to give value to urban design objects and elements in an artefact. This process is carried out for each urban element of *edge, zone, node, landmark and district*. Urban objects as explained in Sub-Section 3.2.1.1 are also captured and recorded. As shown in Table 3.6 below when all elements are in the system, the urban objects and urban elements are organised in rows as indicated in the data structure:

**Table 3.6: Urban elements in rows**

urban object	urban element	parameter	shape				label				weight			
			1	1	1	1	1	1	1	1	1	1	1	1
			u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3
			point	line/ curve	plane	solid	text/ number/ symbol	line/ curve	plane	solid	point area	thickn ess/ colour	hatch/ colour	hatch/ colour
road	path	visibility	0	1	1	0	0	1	0	0	0	1	1	0
		count	0	4	2	0	0	4	0	0	0	7	2	0
		amount	0	0.8	0.4	0	0	0.4	0	0	0	0.7	0.2	0
road	edge	visibility	0	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0
		amount	0	0	0	0	0	0	0	0	0	0	0	0
road	zone	visibility	0	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0
		amount	0	0	0	0	0	0	0	0	0	0	0	0
road	node	visibility	0	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0
		amount	0	0	0	0	0	0	0	0	0	0	0	0
road	landmark	visibility	0	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0
		amount	0	0	0	0	0	0	0	0	0	0	0	0
road	district	visibility	0	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0
		amount	0	0	0	0	0	0	0	0	0	0	0	0

As shown in Table 3.6, *visibility* and *count* for all *shape*, *label* and *weight* items for each urban element and organised in rows are in blue colour, an Input to the system, via manual or technological means.

As explained in Sub-Sections 3.2.1.1 and 3.2.1.2, urban elements are distinguishable as well or can be distinguished using urban objects. In which case, the system is also devised to allow this information to be calibrated.

As shown in Calibration Table 2 below, urban objects can be associated with urban elements. They are organised to fall within the categorisation schema of urban elements. The urban object *o* list can be increased or decreased depending on the focus and objective of the artefact. Urban objects may also be related to more than one urban element. Such as a road which can also be under the element of *path*, *edge*, *zone* and *node*, and a building may be *zone*, *landmark* and *district*. To ensure the diversity of objects is captured Calibration Table 2 in Table 3.7 is a basic taxonomy integrated in the system.

**Table 3.7: Calibration Table 2**

CALIBRATION 2 urban object	data type: [boolean (0 or 1)]						
	urban element						$\beta$
	path	edge	zone	node	landmark	district	
road	1	1	0	0	0	0	0
footpath	0	0	0	0	0	0	0
building	0	0	0	0	0	0	0
street furniture	0	0	0	0	0	0	0
vegetation	0	0	0	0	0	0	0
pedestrian	1	1	1	0	0	0	0
micromobility device	1	1	1	1	0	0	0
motor vehicle	1	0	1	0	0	0	0
<i>o</i>	0	0	0	0	0	0	0

As can be observed the numbers in the calibration table are colour green, indicating it is data that can be adjusted to calibrate the system calculation analyses. The data type is either a 1 which means Yes, and 0 which means No.

As seen in this calibration example: road is Yes under path, edge and zone; footpath is Yes under path and zone; pedestrian is Yes under path, edge and zone; micromobility device is Yes under path, edge zone and node; and motor vehicle is Yes under path, edge and zone.

This is translated as: the artefact will be analysed in terms of its information relating to urban elements of path, edge, zone and node and the associated urban objects of road, footpath, pedestrian, micromobility device and motor vehicle contained in the artefact.

Using the calibration example for path, which has ‘1’ for urban objects of road, pedestrian, micromobility device, and motor vehicle as shown in Table 3.8:

**Table 3.8: Urban Objects associated with Path**

	<b>path</b>
road	<b>1</b>
footpath	<b>0</b>
building	<b>0</b>
street furniture	<b>0</b>
vegetation	<b>0</b>
pedestrian	<b>1</b>
micromobility device	<b>1</b>
motor vehicle	<b>1</b>
o	<b>0</b>

the table shows how the urban objects for *path* are organised in rows as:

**Table 3.9: Urban element path data value**

urban object	urban element	parameter	shape				label				weight				Sum
			point	line/curve	plane	solid	v0	v1	v2	v3	w0	w1	w2	w3	
			u0	u1	u2	u3	text/ number/ symbol	line/ curve	plane	solid	point area	thickn ess/ colour	hatch/ colour	hatch/ colour	
road	path	visibility	0	1	1	0	0	1	0	0	0	1	1	0	2.5
		count	0	4	2	0	0	4	0	0	0	7	2	0	
		amount	0	0.8	0.4	0	0	0.4	0	0	0	0.7	0.2	0	
motor vehicle	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0	
		amount	0	0	0	0	0	0	0	0	0	0	0	0	
pedestrian	path	visibility	0	1	0	0	0	1	0	0	0	1	0	0	1.9
		count	0	6	0	0	0	4	0	0	0	3	0	0	
		amount	0	1.2	0	0	0	0.4	0	0	0	0.3	0	0	
micromobility device	path	visibility	0	0	1	0	0	0	1	0	0	0	1	0	0.7
		count	0	0	1	0	0	0	4	0	0	0	1	0	
		amount	0	0	0.2	0	0	0	0.4	0	0	0	0.1	0	

5.1 PATH DATA VALUE

The calculation, as dictated by the Calibration table 3 and Calibration table 2, results in the Sum total of 5.1 *path data value* as highlighted in Table 3.9.

As observed in the table, the Sum at the end of the row combines the value amount for *shape*, *label* and *weight* for each urban object. In the first row, the Sum data of road-path is 2.5, in colour red to denote the result is autogenerated. Likewise, in the second row, the Sum data of motor vehicle-path is 0, the pedestrian-path is 1.9 and micromobility device-path is 0.7. Each urban object related to the urban element of *path* according to Calibration Table 2 is organised in rows with a Sum data for each urban object at the end of the rows.

At the end of the rows, the data value for each urban object related to the urban element of *path* are further combined. The sums in colour red at the end of the rows are added together to produce the data value for the urban element *path*. Hence, the combined amount = 5.1 as highlighted is the *Path Data Value* of the artefact. This is to be carried out for every urban object to derive the data value for each urban element with each one producing a Sum total data value. As such to show how Calibration Table 2 example looks in the system, recording the urban objects in rows are shown in Table 3.10.

As shown in the table, urban element of *path* has road, motor vehicle, pedestrian and micromobility device resulting in a Sum 5.1 Path Data Value. Urban element of *edge* has road, pedestrian and micromobility device resulting in a Sum 2.6 Edge Data Value. Urban element of *zone* has pedestrian, motor vehicle and micromobility device resulting in a Sum 3.4 Zone Data Value. Urban element of *node* has micromobility device resulting in a Sum 0.2 Node Data Value. *Landmark* and *district* are excluded from the analysis as the calibration table does not have any urban objects as '1'. The sum data of each urban element are added together to produce the artefact's Available Data Value. As shown in Table 3.10, the artefact's graphical value, which is the Available Data Value as highlighted is 11.3. The Available Data Value is an autogenerated calculation and is the result of the artefact's analysis based on the review of

urban objects and urban elements contained in the artefact and the calculations defined in the calibration tables. As well, on the left below the table shows the Visible Element Data, which is the total number of elements contained in the artefact, shown in Table 3.10 as 4. This number is the result as the system identifies only the urban elements of path, edge, zone and node that are present in the artefact. In the last row of urban object-urban element, it can be observed that graphical information relating to *landmark* and *district* are not included. This is to avoid bias in the analysis of artefacts.

**Table 3.10: Available Data Value**

urban object	urban element	parameter	shape				label				weight				Sum	
			point	line/curve	plane	solid	v0	v1	v2	v3	point	thickn	hatch/	hatch/		
			u0	u1	u2	u3	text/ number	line/ curve	plane	solid	area	ess/ colour	colour	colour		
1	road	path	visibility	0	1	1	0	0	1	0	0	0	1	1	0	2.5
		count	0	4	2	0	0	4	0	0	0	7	2	0		
		amount	0	0.8	0.4	0	0	0.4	0	0	0	0.7	0.2	0		
0	motor vehicle	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0		
		amount	0	0	0	0	0	0	0	0	0	0	0	0		
1	pedestrian	path	visibility	0	1	0	0	0	1	0	0	0	1	0	0	1.9
		count	0	6	0	0	0	4	0	0	0	3	0	0		
		amount	0	1.2	0	0	0	0.4	0	0	0	0.3	0	0		
1	micromobility device	path	visibility	0	0	1	0	0	0	1	0	0	0	1	0	0.7
		count	0	0	1	0	0	0	4	0	0	0	1	0		
		amount	0	0	0.2	0	0	0	0.4	0	0	0	0.1	0		
1	3															5.1 PATH DATA VALUE
1	road	edge	visibility	0	1	0	0	0	0	0	0	0	1	0	0	0.6
		count	0	2	0	0	0	0	0	0	0	2	0	0		
		amount	0	0.4	0	0	0	0	0	0	0	0.2	0	0		
1	pedestrian	edge	visibility	0	1	1	0	0	0	0	0	0	1	1	0	2
		count	0	8	1	0	0	0	0	0	0	1	1	0		
		amount	0	1.6	0.2	0	0	0	0	0	0	0.1	0.1	0		
0	micromobility device	edge	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0		
		amount	0	0	0	0	0	0	0	0	0	0	0	0		
1	2															2.6 EDGE DATA VALUE
1	pedestrian	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	1.7
		count	0	0	5	0	0	0	5	0	0	0	2	0		
		amount	0	0	1	0	0	0	0.5	0	0	0	0.2	0		
1	motor vehicle	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	1
		count	0	0	3	0	0	0	2	0	0	0	2	0		
		amount	0	0	0.6	0	0	0	0.2	0	0	0	0.2	0		
1	micromobility device	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	0.7
		count	0	0	1	0	0	0	4	0	0	0	1	0		
		amount	0	0	0.2	0	0	0	0.4	0	0	0	0.1	0		
1	3															3.4 ZONE DATA VALUE
1	micromobility device	node	visibility	0	0	1	0	0	0	1	0	0	0	0	0	0.2
		count	0	0	1	0	0	0	1	0	0	0	0	0		
		amount	0	0	0.2	0	0	0	0	0	0	0	0	0		
1	1															0.2 NODE DATA VALUE
0	0	landmark	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0		
		amount	0	0	0	0	0	0	0	0	0	0	0	0		
0	0															0.0 LANDMARK DATA VALUE
0	0	district	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0		
		amount	0	0	0	0	0	0	0	0	0	0	0	0		
0	0															0.0 DISTRICT DATA VALUE
4	VISIBLE ELEMENT DATA													11.3 AVAILABLE DATA VALUE		

This concludes the first phase of the artefact's evaluation method, which analyses and quantifies the artefact's data value. The research illustrates how this can also be applicable across all scales, dimensions and types of artefacts. The mechanism allows for higher-dimensional graphics to be evaluated using the same logic.

### **3.3.3 DATA EVALUATION AGAINST STAKEHOLDER REQUIREMENTS**

The second phase of the Evaluation Method is entirely autogenerated producing the evaluation results. The process involves using the Sum data values from the first phase. These are used to evaluate and determine if the values are suitable for the visual communication needs of stakeholders involved in the project. The literature review shows that evidence on the efficacy of artefacts with information relevant to the audience is limited.

It is also inadequate to conclude that an artefact is most effective when data is jam-packed. The measurement for visual communicative quality is difficult and any data value becomes arbitrary without reference to target audience and becomes non-intentional. Effectiveness means in this case is that the artefact must be put to account against a specific requirement to ensure a good fit. Using the artefact's quantified data value provides an opportunity to produce an evidence-based evaluation metric that measures and quantifies what a good fit is.

### 3.3.3.1 Stakeholders' Requirements



The system of values to evaluate communication capacity is a variable. They were set by selecting a group of stakeholders, whose requirements were identified based on their areas of focus, as shown in Calibration Table 1 in Table 3.11. Using a provisional system of values with adjustable features the research can demonstrate how the results of an evaluation are derived. Therefore, this process requires stakeholders' requirements/needs to be identified as well as quantified based on the same data type of *path*, *edge*, *zone*, *node*, *landmark* and *district*.

Based on the types of stakeholders often involved in urban design projects, stakeholders' requirements of urban elements of *path*, *edge*, *zone*, *node*, *landmark* and *district* are based on assumptions. Assumptions are made as to the types of information that are mostly of importance to the stakeholder and generally accepted as true. As an example, a commercial building owner may be more concerned with *zone*, *landmark* and *district*. The *edge* element can include urban objects such as building boundary and road kerb. *Zone* element may include the building area and active frontage area. *Path* element may include pedestrian path. This list can differ, however, to the requirements of an engineer who will require more details on *edge*, *zone* and *path* and may be less concerned with *node*, *landmark* and *district*. Whereas a city planner's requirements may be more focused on *path*, *zone* and *district*.

As stakeholders' requirements can vary or can be subject to interpretation, the system is designed to allow this to be adjusted. Calibration Table 1 shown in Table 3.11 is a device to define urban design information priorities for each stakeholder. To demonstrate, the table below shows an example of a list of project stakeholders.

**Table 3.11: Calibration table 1. Defines required elements by each stakeholder**

CALIBRATION 1		data type: [boolean (0 or 1)]							REQUIRED ELEMENT DATA
$\beta$									
urban stakeholder	path	edge	zone	node	landmark	district	$\beta$		
city planner	1	0	1	0	0	1	0	3	
urban designer	1	1	1	1	1	0	0	5	
engineer	1	1	0	0	0	0	0	2	
pedestrian	1	0	1	1	0	0	0	3	
micromobility device user	1	0	1	0	0	0	0	2	
motor vehicle driver	1	1	0	0	0	0	0	2	
building owner	0	0	1	0	1	1	0	3	
$\sigma$	0	0	0	0	0	0	0	0	

Like Calibration Table 2, to indicate which urban elements are required by individual stakeholders, 1 = yes and 0 = no.

As example it can be observed that pedestrian is allocated as  $path=1$ ,  $zone=1$ , and  $node=1$ . Based on assumptions the system identifies that a pedestrian stakeholder is more concerned with  $path$ ,  $zone$  and  $node$ .  $Path$  may include ‘urban objects’ of wayfinding, pedestrian links and walkable street networks.  $Zone$  may include high pedestrian areas, public outdoor amenities, and green streetscapes.  $Node$  may include train stations, destination points, and so on.

In the Calibration Table 1, as well the list of stakeholders can be increased. Green numbers indicate the 1=yes and 0=no requirements can be adjusted. At the end of the row, the numbers are added to produce the quantified total requirement for each stakeholder called Required Element Data.

Given the assumptions of stakeholders’ visual requirements, the quantified requirement data will be used to score the data values derived from the analysis in phase one.

### 3.3.3.2 Penalty Calculation



The evaluation formula involves assigning penalties. A penalty is given if data requirement is not met. As example, a penalty is given if data is not visible but is required by the stakeholder. Similarly, a penalty is also given if the data is visible but not required by the stakeholder. Therefore, if data is irrelevant, too many or data is lacking, a penalty will be assigned against the data based on stakeholder requirements. In the table below, using the same example of data values in phase 1, the Evaluation table shows the Sum data value for each urban element is carried across the rows to the evaluation phase 2. The urban element values are highlighted. In the Evaluation table, these are translated to data *value less penalty*.

In Table 3.12 under the word Evaluation, the first column contains information carried across from the phase 1 analysis table, which is the reference data as ‘urban object-urban element’, i.e. *road-path*, *motor vehicle-path*, *pedestrian-path* and *micromobility device-path*.

**Table 3.12: Data value carried over from analysis to evaluation**

Sum	EVALUATION	
	System calculates:	
	urban object-urban element	urban element visibility
2.5	road-path	1
0	motor vehicle-path	0
1.9	pedestrian-path	1
0.7	micromobility device-path	1
5.1 PATH DATA VALUE	DATA PENALTY	
	PATH DATA VALUE LESS PENALTY	
	ELEMENT PENALTY	
0.6	road-edge	1
2	pedestrian-edge	1
0	micromobility device-edge	0
2.6 EDGE DATA VALUE	DATA PENALTY	
	EDGE DATA VALUE LESS PENALTY	
	ELEMENT PENALTY	
1.7	pedestrian-zone	1
1	motor vehicle-zone	1
0.7	micromobility device-zone	1
3.4 ZONE DATA VALUE	DATA PENALTY	
	ZONE DATA VALUE LESS PENALTY	
	ELEMENT PENALTY	
0.2	micromobility device-node	1
0.2 NODE DATA VALUE	DATA PENALTY	
	NODE DATA VALUE LESS PENALTY	
	ELEMENT PENALTY	
0	0-landmark	0
0.0 LANDMARK DATA VALUE	DATA PENALTY	
	LANDMARK DATA VALUE LESS PENALTY	
	ELEMENT PENALTY	
0	0-district	0
0.0 DISTRICT DATA VALUE	DATA PENALTY	
	DISTRICT DATA VALUE LESS PENALTY	
	ELEMENT PENALTY	

The second column ‘urban element visibility’ in the evaluation table is data that is either ‘1’ as Yes, or ‘0’ as No. As shown for urban element *path*, *road-path*, *micromobility device-path*, and *pedestrian-path* are ‘1’, whilst *motor vehicle-path* is ‘0’. These are autogenerated from the results of phase 1. As such, it identifies that *motor vehicle-path* is data that is lacking from the artefact. The numbers are black to show they are system calculations. This is established for each urban object and urban element identified in phase 1 as shown along the length of the column ‘urban element visibility’. It simply establishes if the data is contained in the artefact or not.

The example below for *path* data shows how the evaluation and penalty is calculated against each stakeholder. Table 3.13 shows how stakeholders are organised in columns.

**Table 3.13: Urban objects-path data evaluation**

Sum	EVALUATION									
	System calculates: urban object-urban element	urban element visibility	city planner	urban designer	engineer	pedestrian	micromobility device user	motor vehicle driver	building owner	
2.5	road-path	1	0	0	0	0	0	0	0	-1
0	motor vehicle-path	0	-1	-1	-1	-1	-1	-1	-1	0
1.9	pedestrian-path	1	0	0	0	0	0	0	0	-1
0.7	micromobility device-path	1	0	0	0	0	0	0	0	-1
		DATA PENALTY	-1	-1	-1	-1	-1	-1	-1	-3
	5.1 PATH DATA VALUE	PATH DATA VALUE LESS PENALTY	4.1	4.1	4.1	4.1	4.1	4.1	4.1	-1
		ELEMENT PENALTY	0	0	0	0	0	0	0	-1

As typical in the system, the red numbers are autogenerated results. The columns list each stakeholder which has formulas based on the Calibration table 1.

As Calibration table 1 shows *path* is yes for all stakeholders except *building owner*. As such in the Evaluation table in the row ‘*path data value less penalty*’, under the column *building owner*, penalty as ‘-1’ is autogenerated.

Whereas based on the defined requirements for all other stakeholders that require the urban element *path*, the *Path Data Value* as highlighted from phase 1 the value is carried across as a score for the data.

However, as shown in the table, the *motor vehicle-path* with 0' data will also incur a penalty against the *Path Data Value* for each stakeholder that requires the *path* data to be contained in the artefact. Therefore, the *path data value* = 5.1, from the analysis phase 1 will be calculated as 5.1 less 'data penalty -1' as shown in the row 'data penalty' and against each stakeholder columns. The *path data value less penalty* for each stakeholder = 4.1.

As example a city planner has path = 1 (Yes, in Calibration 1), therefore:

<u>Urban object-element</u>	<u>Visible? (1/0)</u>	<u>Penalty</u>	
road-path	1 (Yes)	=0	(no penalty)
motor vehicle-path	0 (No)	=1	(penalty)
pedestrian-path	1 (Yes)	=0	(no penalty)
micromobility device-path	<u>1 (Yes)</u>	<u>=0</u>	(no penalty)
TOTAL PENALTY		=1	(minus)

Note: As motor vehicle-path is not visible or not contained in the artefact, a penalty is assigned due to the requirement of city planner not being met.

This penalty calculation is the process by which the research evaluates in fine grain how each urban element such as *path* is communicated in the artefact, giving value to the communication, or determines whether it needs to be communicated at all to the target stakeholder, and considered as too much information.

In summary, the rows in the table show:

*Data Penalty* is the total penalty assigned to the artefact against each *urban element data value* based on the requirements indicated in Calibration Table 1 for each stakeholder. However, this is only applied if the urban element is required by the stakeholder and some urban objects are missing.

*Path Data Value Less Penalty* is the evaluation of data performance for each stakeholder. Taking the *Path Data Value* from phase 1, the system auto-calculates any penalties under *Data Penalty*, by subtracting the *Data Penalty* from the *Path Data Value*. However, this is only calculated if the urban element is required by the stakeholder. Otherwise, if not required but is contained in the artefact, the result is an automatic penalty of ‘-1’.

*Element Penalty* is a penalty that simply indicates if the urban element is required or not by the stakeholder, 0 for no penalty as it meets the requirement and -1 if it doesn’t meet the requirement. As example in Table 3.14 showing when the urban element is missing in the artefact and when it is required by the stakeholder.

**Table 3.14: Landmark and district data evaluation**

Sum	EVALUATION										
	System calculates:		urban object-urban element	urban element visibility	city planner	urban designer	engineer	pedestrian	micromobility device user	motor vehicle driver	building owner
0	0-landmark	0		0	-1	0	0	0	0	0	-1
		DATA PENALTY		0	-1	0	0	0	0	0	-1
	0.0 LANDMARK DATA VALUE	LANDMARK DATA VALUE LESS PENALTY		0	-1	0	0	0	0	0	-1
		ELEMENT PENALTY		0	-1	0	0	0	0	0	-1
0	0-district	0		-1	0	0	0	0	0	0	-1
		DATA PENALTY		-1	0	0	0	0	0	0	-1
	0.0 DISTRICT DATA VALUE	DISTRICT DATA VALUE LESS PENALTY		-1	-1	0	0	0	0	0	-1
		ELEMENT PENALTY		-1	0	0	0	0	0	0	-1

As shown in the table, *landmark* and *district* data are clearly not contained in the artefact as shown in the Sum data value from phase 1 and highlighted as Sum = 0 in red. In Calibration table 1, it indicates that *landmark* is required by urban designer and building owner. Therefore, its absence incurs a penalty against the data under *urban designer* and under *building owner* columns, but 0 or no penalty under other stakeholders that do not consider this data a priority.

Similarly for *district*, Calibration table 1 indicates that district is required by *city planner* and *building owner*. Therefore, the absence of district data incurs a penalty under *city planner* and *building owner* as shown in the table. The entire Evaluation table is shown below Table 3.15.

**Table 3.15: Evaluation table penalty calculation**

EVALUATION		System calculates:									
urban object-urban element	urban element visibility	city planner	urban designer	engineer	pedestrian	micromobility device user	motor vehicle driver	building owner			
road-path	1	0	0	0	0	0	0	0	-1		
motor vehicle-path	0	-1	-1	-1	-1	-1	-1	-1	0		
pedestrian-path	1	0	0	0	0	0	0	0	-1		
micromobility device-path	1	0	0	0	0	0	0	0	-1		
	DATA PENALTY	-1	-1	-1	-1	-1	-1	-1	-3	-1	
5.1 PATH DATA VALUE	PATH DATA VALUE LESS PENALTY	4.1	4.1	4.1	4.1	4.1	4.1	4.1	-1		
	ELEMENT PENALTY	0	0	0	0	0	0	0	-1		
road-edge	1	-1	0	0	-1	-1	0	-1			
pedestrian-edge	1	-1	0	0	-1	-1	0	-1			
micromobility device-edge	0	0	-1	-1	0	0	-1	0			
	DATA PENALTY	-2	-1	-1	-2	-2	-1	-2	-2	-1	
2.6 EDGE DATA VALUE	EDGE DATA VALUE LESS PENALTY	-1	1.6	1.6	-1	-1	-1	1.6	-1		
	ELEMENT PENALTY	-1	0	0	-1	-1	0	0	-1		
pedestrian-zone	1	0	0	-1	0	0	-1	0			
motor vehicle-zone	1	0	0	-1	0	0	-1	0			
micromobility device-zone	1	0	0	-1	0	0	-1	0			
	DATA PENALTY	0	0	-3	0	0	-3	-1	0	3.4	
3.4 ZONE DATA VALUE	ZONE DATA VALUE LESS PENALTY	3.4	3.4	-1	3.4	3.4	3.4	-1	3.4		
	ELEMENT PENALTY	0	0	-1	0	0	-1	0	0		
micromobility device-node	1	-1	0	-1	0	-1	-1	-1	-1		
	DATA PENALTY	-1	0	-1	0	-1	-1	-1	-1	-1	
0.2 NODE DATA VALUE	NODE DATA VALUE LESS PENALTY	-1	0.2	-1	0.2	-1	-1	-1	-1		
	ELEMENT PENALTY	-1	0	-1	0	-1	-1	-1	-1		
0-landmark	0	0	-1	0	0	0	0	0	-1		
	DATA PENALTY	0	-1	0	0	0	0	0	-1	-1	
0.0 LANDMARK DATA VALUE	LANDMARK DATA VALUE LESS PENALTY	0	-1	0	0	0	0	0	-1	-1	
	ELEMENT PENALTY	0	-1	0	0	0	0	0	-1		
0-district	0	-1	0	0	0	0	0	0	-1		
	DATA PENALTY	-1	0	0	0	0	0	0	-1	-1	
0.0 DISTRICT DATA VALUE	DISTRICT DATA VALUE LESS PENALTY	-1	0	0	0	0	0	0	-1	-1	
	ELEMENT PENALTY	-1	0	0	0	0	0	0	-1		

The Evaluation table above shows the penalty calculation for all the urban element data values produced in the analysis in phase 1. The calculation process explained in this Sub-Section is carried out automatically for all urban elements in the artefact organised in rows, shown as highlighted. These are tabulated with stakeholders organised in columns within the

Evaluation section of the table. The results of the penalty calculation are autogenerated as the Input in Analysis 1 is recorded. The calculation is based on the requirements indicated for each stakeholder in Calibration table 1.

### 3.3.4 EVALUATION RESULTS AND CALCULATION



The last part of phase 2 Evaluation consists of the evaluation result. This is entirely autogenerated. The evaluation result has three parts, the *Scoring*, the *Rating*, and the *Result* as shown in Table 3.16.

**Table 3.16: Evaluation results**

<b>SCORING</b>							
STAKEHOLDER DATA VALUE	4.5	8.3	3.7	6.7	5.5	3.7	-1.6
VALUABLE DATA	40%	73%	33%	59%	49%	33%	-14%
<b>RATING</b>							
REQUIRED ELEMENT DATA	3	5	2	3	2	2	3
TOTAL ELEMENT PENALTY	-3	-1	-2	-1	-2	-2	-3
ELEMENT DATA FAILURE	75%	25%	50%	25%	50%	50%	75%
Rated As:	Inappropriate	Acceptable	Inappropriate	Acceptable	Inappropriate	Inappropriate	Inappropriate
<b>RESULT</b>	<b>60%</b>	<b>73%</b>	<b>67%</b>	<b>59%</b>	<b>49%</b>	<b>67%</b>	<b>100%</b>
	Inappropriate	Acceptable	Inappropriate	Acceptable	Inappropriate	Inappropriate	Inappropriate

The Scoring and the Rating is a two-stage validation process. This is shown here as *Scoring* along the top row highlighted in purple and *Rating* in the middle row also highlighted in purple, and the *Result* along the bottom row which produces the integrated result as *Scoring* + *Rating* highlighted in blue.

#### 3.3.4.1 Scoring

The first stage of the validation process is *Scoring*. *Scoring* has two items. One is the *stakeholder data value*. This is the sum of all the values for each urban element less the penalty as explained in 3.2.3.2 Penalty Calculation. This has a decimal number as data type.

Two is the *valuable data*. This is the percentage of data contained in the artefact that is considered valuable to each stakeholder. This is produced by taking the *Available Data Value*

in the phase 1 analysis and calculating what percentage of this value is considered as meeting the explicit requirement of the stakeholder, called the *stakeholder data value*.

To demonstrate, given the *Available Data Value* = 11.3, the calculation for *valuable data* is:

$$\text{valuable data \%} = \frac{\text{stakeholder data value}}{\text{Available Data Value}} \quad | \quad 39.8\% = \frac{4.5}{11.3}$$

39.8% is rounded to the nearest percent = 40%

### 3.3.4.2 Rating

The second stage of the validation process is *Rating*. *Rating* is a simple declaration that indicates whether the artefact is Acceptable or Inappropriate. *Rating* has four items: *required element data*, *total element penalty*, *element data failure* and *rated as*.

*Required element data* is the number dictated in Calibration table 1.

*Total element penalty* is the total penalty incurred against each urban element that does not meet the requirement for each stakeholder defined in Calibration table 1. Similar to the scoring penalty process, each urban element is evaluated against the stakeholder's requirement for that urban element. A penalty is given if the urban element is missing but is required by the stakeholder. As well, a penalty is also given if the urban element is available but not required by the stakeholder. As shown in the Evaluation table, Table ##, these penalties are itemised in rows entitled *Element Penalty* and as explained in 3.2.3.2. If there is no penalty, it simple states a 0. The *Total element penalty* is the sum of the *Element Penalty* for each stakeholder.

*Element data failure* is the percentage of the information contained in the artefact that does not meet the stakeholder's requirements. This is calculated by evaluating the *Visible Element Data* produced in phase 1 analysis. The evaluation is done by taking the *Visible*

*Element Data* and calculating what percentage of this is considered as not meeting the explicit requirement of the stakeholder, called the *element data failure*. The data type is a percentage.

To demonstrate, given the *Visible Element Data* = 4, the calculation for *element data failure* is:  $\text{total element penalty} \div \text{Visible Element Data} \times 100 = \text{element data failure \%}$ .

$$\text{element data failure \%} = \frac{\text{total element penalty}}{\text{Visible Element Data}}$$

For *city planner*, the *element data failure* is shown as:

$$75\% = \frac{3}{4}$$

*Rated as* is a basic interpretation of the *element data failure* that determines if the artefact is *Acceptable* or *Inappropriate*. The system is designed to identify the artefact as *Acceptable* if the *element data failure* is less than 50%. Otherwise, if the *element data failure* is equal to or greater than 50%, the system identifies the artefact as *Inappropriate*.

### 3.3.4.3 Result

*Result* is an integration of the *Scoring* and the *Rating* into a coherent evaluation result of the artefact's efficacy in meeting stakeholders' visual communication requirements. As such, if the artefact is rated as:

*Acceptable*, the *Result* shows the *valuable data* + '*Acceptable*'.

*Inappropriate*, the *Result* shows (100% less *valuable data*) + '*Inappropriate*'.

Because *valuable data* is considered data that is meeting the requirement, hence a positive outcome, it is associated with the positive outcome of *Acceptable*. However, if the *Result* shows an *Inappropriate* result, it will instead give the percentage of the data that is not meeting the requirement, hence calculated as 100% less *valuable data*.

As shown in Table 3.17 below, under *urban designer*, the artefact is evaluated as 73% *Acceptable*. The percentage of 73% corresponds with the *valuable data* of 73% under *Scoring*. Similarly for *pedestrian*, the artefact is evaluated as 59% *Acceptable*, in which 59% corresponds with the *valuable data* of 59% under *Scoring*. However, under the other stakeholders' columns in which the artefact is evaluated as *Inappropriate*, the percentage of inappropriateness of the artefact will show instead as the *Result*, i.e. 100% minus *valuable data*.

**Table 3.17: Evaluation Results**

EVALUATION								
System calculates:								
urban object-urban element	urban element visibility	city planner	urban designer	engineer	pedestrian	micromobility device user	motor vehicle driver	building owner
<b>SCORING</b>								
STAKEHOLDER DATA VALUE		4.5	8.3	3.7	6.7	5.5	3.7	-1.6
VALUABLE DATA		40%	73%	33%	59%	49%	33%	-14%
<b>RATING</b>								
REQUIRED ELEMENT DATA		3	5	2	3	2	2	3
TOTAL ELEMENT PENALTY		-3	-1	-2	-1	-2	-2	-3
ELEMENT DATA FAILURE		75%	25%	50%	25%	50%	50%	75%
Rated As:		Inappropriate	Acceptable	Inappropriate	Acceptable	Inappropriate	Inappropriate	Inappropriate
RESULT		60%	73%	67%	59%	49%	67%	100%
		Inappropriate	Acceptable	Inappropriate	Acceptable	Inappropriate	Inappropriate	Inappropriate

The complete Evaluation in Table 3.18 shows the data values from Phase 1 and calculations:

**Table 3.18: Evaluation Table**

		EVALUATION								
		System calculates:								
urban object-urban element		urban element visibility	city planner	urban designer	engineer	pedestrian	micromobility device user	motor vehicle driver	building owner	
	road-path	1	0	0	0	0	0	0	-1	
	motor vehicle-path	0	-1	-1	-1	-1	-1	-1	0	
	pedestrian-path	1	0	0	0	0	0	0	-1	
	micromobility device-path	1	0	0	0	0	0	0	-1	
5.1 PATH DATA VALUE	DATA PENALTY		-1	-1	-1	-1	-1	-1	-3	
	PATH DATA VALUE LESS PENALTY		4.1	4.1	4.1	4.1	4.1	4.1	-1	
	ELEMENT PENALTY		0	0	0	0	0	0	-1	
	road-edge	1	-1	0	0	-1	-1	0	-1	
	pedestrian-edge	1	-1	0	0	-1	-1	0	-1	
	micromobility device-edge	0	0	-1	-1	0	0	-1	0	
2.6 EDGE DATA VALUE	DATA PENALTY		-2	-1	-1	-2	-2	-1	-2	
	EDGE DATA VALUE LESS PENALTY		-1	1.6	1.6	-1	-1	1.6	-1	
	ELEMENT PENALTY		-1	0	0	-1	-1	0	-1	
	pedestrian-zone	1	0	0	-1	0	0	-1	0	
	motor vehicle-zone	1	0	0	-1	0	0	-1	0	
	micromobility device-zone	1	0	0	-1	0	0	-1	0	
3.4 ZONE DATA VALUE	DATA PENALTY		0	0	-3	0	0	-3	0	
	ZONE DATA VALUE LESS PENALTY		3.4	3.4	-1	3.4	3.4	-1	3.4	
	ELEMENT PENALTY		0	0	-1	0	0	-1	0	
	micromobility device-node	1	-1	0	-1	0	-1	-1	-1	
0.2 NODE DATA VALUE	DATA PENALTY		-1	0	-1	0	-1	-1	-1	
	NODE DATA VALUE LESS PENALTY		-1	0.2	-1	0.2	-1	-1	-1	
	ELEMENT PENALTY		-1	0	-1	0	-1	-1	-1	
	0-landmark	0	0	-1	0	0	0	0	-1	
0.0 LANDMARK DATA VALUE	DATA PENALTY		0	-1	0	0	0	0	-1	
	LANDMARK DATA VALUE LESS PENALTY		0	-1	0	0	0	0	-1	
	ELEMENT PENALTY		0	-1	0	0	0	0	-1	
	0-district	0	-1	0	0	0	0	0	-1	
0.0 DISTRICT DATA VALUE	DATA PENALTY		-1	0	0	0	0	0	-1	
	DISTRICT DATA VALUE LESS PENALTY		-1	0	0	0	0	0	-1	
	ELEMENT PENALTY		-1	0	0	0	0	0	-1	
11.3 AVAILABLE DATA VALUE	<b>SCORING</b>									
	STAKEHOLDER DATA VALUE		4.5	8.3	3.7	6.7	5.5	3.7	-1.6	
	VALUABLE DATA		40%	73%	33%	59%	49%	33%	####	
	<b>RATING</b>									
	REQUIRED ELEMENT DATA		3	5	2	3	2	2	3	
	TOTAL ELEMENT PENALTY		-3	-1	-2	-1	-2	-2	-3	
	ELEMENT DATA FAILURE		75%	25%	50%	25%	50%	50%	75%	
	Rated As:		Inappropriate	Acceptable	Inappropriate	Acceptable	Inappropriate	Inappropriate	Inappropriate	
	<b>RESULT</b>		60%	73%	67%	59%	49%	67%	100%	
			Inappropriate	Acceptable	Inappropriate	Acceptable	Inappropriate	Inappropriate	Inappropriate	

### 3.3.1 SYSTEM CATALOGUE AND CALIBRATION TABLES

In summary, the calibration mechanisms in the system are illustrated in Table 3.19 and the catalogue of items are in Table 3.20:

Table 3.19: Calibration Tables

CALIBRATION 1		data type: [boolean (0 or 1)]							REQUIRED ELEMENT DATA
$\beta$		path	edge	zone	node	landmark	district	$\epsilon$	
urban stakeholder									
city planner		1	0	1	0	0	1	0	3
urban designer		1	1	1	0	1	0	0	4
engineer		1	1	0	1	0	0	0	3
pedestrian		1	0	1	0	0	0	0	2
micromobility device u		1	0	1	0	0	0	0	2
motor vehicle driver		1	1	0	1	0	0	0	3
building owner		0	0	1	0	1	1	0	3
$\sigma$		0	0	0	0	0	0	0	0

CALIBRATION 2		data type: [boolean (0 or 1)]						
urban object	urban element							
	path	edge	zone	node	landmark	district	$\epsilon$	
road	1	1	1	1	0	0	0	
footpath	1	1	1	0	0	0	0	
building	0	0	1	0	1	1	0	
street furniture	0	0	1	0	0	0	0	
vegetation	0	1	1	1	0	0	0	
pedestrian	1	1	1	1	0	0	0	
micromobility device	1	1	1	0	0	0	0	
motor vehicle	1	1	1	0	0	0	0	
o	0	0	0	0	0	0	0	

CALIBRATION 3		shape				label				weight				score
data type	drawing element parameter	u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3	
boolean (0 or 1)	visibility	0	1	1	0	0	1	0	0	0	1	1	0	
percentage	weighting	10%	20%	20%	0%	5%	10%	10%	0%	5%	10%	10%	0%	100%
integer (= or > than 0)	amount	0	4	2	0	0	4	0	0	0	7	2	0	
	calculation	0	0.8	0.4	0	0	0.4	0	0	0	0.7	0.2	0	2.5

Phase 1 Analysis can accommodate changes to:

- Description #3, Description #4, Description #6
- Calibration 2 & Calibration 3

Phase 2 Evaluation can accommodate changes to:

- Description #5
- Calibration 1

Cataloguing Table

	description #1	description #2	description #3	description #4	description #5	description #6	visual data #1	visual data #2	visual data #3	visual data #4	visual data #5	visual data #6
	project	artefact	urban object	urban element	urban stakeholder	data value of drawing element	drawing element	shape	label	weight	space	parameter
symbol	$\tau$	$\alpha$	$\sigma$	$\beta$	$\sigma$		$k$	$u$	$v$	$w$	$y$	$z$
index	$m$	$n$	$o$	$p$	$q$		$k$	$i$	$i$	$i$	$j$	$s$
0	project 1	plan	road	path	city planner	50%	shape	point	text/ number/ symbol	point area	zero-dimension	visibility
1	project 2	cross-section	footpath	edge	urban designer	25%	label	line/ curve	line/ curve	thickness/ colour	one-dimension	weighting
2	project 3	elevation	building	zone	engineer	25%	weight	plane	plane	hatch/ colour	two-dimension	amount
3	project 4	pattern	street furniture	node	pedestrian			solid	solid	hatch/ colour	three-dimension	
4		urban context 2D-3D	vegetation	landmark	micromobility device user						four-dimension (time)	
5			pedestrian	district	motor vehicle driver							
6			micromobility device	$\beta$	building owner							
7			motor vehicle	Total								
8				6								
$\varepsilon$												

Table 3.20: Catalogue of items in the system



# Chapter 4: Research Experiments

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This chapter focuses on presenting the experiments conducted to test the algorithmic system detailed in Chapter 3, employing statistical analysis to evaluate the performance of the artefacts. Section 1 introduces the experimental approach and outlines the selection criteria of the four original artefacts—Artefacts 1 to 4—utilised to demonstrate the system's functionality. It also defines the scope of the experiments by establishing the system parameters as outlined in the Calibration tables.

Section 4.2 details Experiment 1, which comprises three artefact evaluations: the first artefact is Artefact 1. The second is Artefact 1 Test 1, which represents the first Artefact 1 variation; and the third, Artefact 1 Test 2, represents the second Artefact 1 variation. This section concludes with a summary of the three evaluations conducted for Experiment 1.

Similarly, Section 4.3 focuses on Experiment 2, evaluating Artefact 2, and adheres to the same structure as Experiment 1. Section 4.4 presents Experiment 3, which evaluates Artefact 3, while Section 4.5 presents Experiment 4, dedicated to Artefact 4, following the established format. In total, this chapter encompasses four experiments, each consisting of three evaluations of the respective artefacts, thereby providing a demonstration of the algorithmic system's functionality.

## 4.1 INTRODUCTION

To test the system presented in Section 3.3 The Evaluation Method, the research selects four artefacts to carry out graphical information analyses and artefact evaluations. The artefacts selected are case samples from urban design projects for the design and implementation of micromobility infrastructure in Sydney. They were selected based on the following criteria: 1)

complex project - involving various stakeholder groups with diverse objectives and viewpoints; 2) project scale –infrastructure that involves a large area or regional distance; 3) project impact – transformative urban design and/or a current cross-governmental priority.

## THE EXPERIMENT

Each artefact 1, 2, 3 and 4 will undergo an experiment. The experiment will consist of a statistical analysis of the artefact, and the *system artefact analysis* and *system artefact evaluation*. The statistical analysis of the artefact involves identifying graphical data based on the shape algebra, label and weight data. This information will be used to populate the *visibility* and *count* required in the *system artefact analysis*. The system also calculates and evaluates this data based on requirements for each stakeholder. The evaluation will result in a score and a rating.

Based on the results information, the experiment will proceed to further examine the impact if the artefact is changed. To do this each artefact is graphically tailored to improve the score and the rating to suit a stakeholder. For the purpose of an evidence-based testing the system demonstrates that an artefact can be intentionally and precisely developed to suit requirements. The research experiment proceeded to improve the results by adapting the artefact to meet the individual requirements for each stakeholder.

For comparison, the research selects *urban designer* and *micromobility device user* to use as focus stakeholders. The research experiments on making changes to the original artefact to improve the performance scoring and rating of the artefact to suit *urban designer* and *micromobility device user*.

For Test 1, the artefact will be customised for an *urban designer*. Graphical data will satisfy the Required Element Data for *urban designer* based on Calibration Table 1. This artefact will then be put through the system artefact analysis and evaluation to produce the

score and rating result for Test 1. For Test 2, the artefact will be customised for a *micromobility device user*. As well, graphical data will satisfy the Required Element Data based on Calibration Table 1. This artefact will also be put through the system artefact analysis and evaluation to produce the score and rating result for Test 2. To conclude the experiment will make a visual comparison of the original artefact, the Test 1 artefact and the Test 2 artefact showing the scores and rating results. The research will examine and interrogate each of the four artefacts using this process. For the purpose of tailoring the analysis and avoiding bias, the experiments in this chapter will use the following formulas in the calibration tables for use in the system:

#### 4.1.1 SYSTEM CALIBRATION 1

**Table 4.1: Calibration Table 1 - Experiment**

CALIBRATION 1		data type: [boolean (0 or 1)]							REQUIRED ELEMENT DATA
$\beta$		path	edge	zone	node	landmark	district	$\beta$	
urban stakeholder									
city planner	1	0	1	0	0	0	0	0	2
urban designer	1	1	1	1	0	0	0	0	4
engineer	1	1	0	0	0	0	0	0	2
pedestrian	1	0	1	1	0	0	0	0	3
micromobility device user	1	0	1	0	0	0	0	0	2
motor vehicle driver	1	1	0	0	0	0	0	0	2
building owner	0	0	1	0	0	0	0	0	1
$\sigma$	0	0	0	0	0	0	0	0	0

Calibration table 1 as shown has the urban elements of landmark and district turned off. This will be used for Experiments 1 to 4, as Artefacts 1 to 3 has small-scale designs. The artefacts focus on the communication of information on smaller areas of the city. By leaving landmark and district turned on for artefacts on small-scale projects that are being evaluated the evaluation will create a bias. The ‘0’ (No) against all landmark and district will also not suffice as the value for Required Element Data will have a value that will as well result in a bias. Therefore, for Artefact 4 which focuses on conveying a large-scale design and involves

information relating to a larger geographic area, the urban elements of landmark and district will be turned on, while the urban element of edge will be turned off to eliminate a bias as the urban element of edge does not easily feature in large scale projects.

Calibration Table 1 also shows that for each of the stakeholders, stakeholder information requirements are allocated. This is by no means definitive but simply for the purpose of demonstrating the use of the system. The artefact will be evaluated on its performance in communicating the following: for city planner, path and zone; for urban designer, path, edge, zone and node; for engineer, path and edge; for pedestrian, path, zone and node; for micromobility device user, path and zone; for motor vehicle driver, path and edge; and for building owner, zone. As well, this list is not definitive. For each stakeholder the Required Element Data is the autogenerated sum result for each stakeholder requirements. The stakeholders' list is not exhaustive and definitive. They've been chosen to demonstrate how the system can accommodate local and public perspectives. As well to demonstrate that also within both public and private perspectives, the information requirements vary, and communication artefacts can be more nuanced to improve performance.

#### **4.1.2 System Calibration 2**

To correspond with the urban elements to be examined and identified in Calibration table 1, Calibration table 2 as shown in Table 4.2 also has the urban elements of landmark and district turned off. This will be used for the evaluation in Experiments 1 to 3. For Experiment 4, the urban elements of landmark and district will be turned on whilst the urban element of edge will be turned off to correspond with Calibration table 1 proposed for Experiment 4.

Calibration table 2 also shows the urban objects selected as part of the evaluation. As Experiments 1 to 4 examine artefacts that focus on micromobility projects, to avoid a bias and to keep a narrower evaluation focus, the urban objects selected are those that feature usually in

artefacts developed for micromobility projects so that urban objects help provide context in urban designs. For example, to understand cycleway design, the road and footpath are important considerations. As well, the list of proposed urban objects in Calibration table 2 for use in these experiments is not exhaustive, and description is not definitive as the system accommodates changes to these parameters. The list can be adjusted and increased. This is simply to demonstrate how calibration and the system works.

**Table 4.2: Calibration Table 2 - Experiment**

CALIBRATION 2 urban object	data type: [boolean (0 or 1)]						
	urban element				landmark	district	$\beta$
	path	edge	zone	node			
road	1	1	0	0	0	0	0
footpath	1	0	1	0	0	0	0
building	0	0	0	0	0	0	0
street furniture	0	0	0	0	0	0	0
vegetation	0	0	0	0	0	0	0
pedestrian	1	1	1	0	0	0	0
micromobility device	1	1	1	1	0	0	0
motor vehicle	1	0	1	0	0	0	0
o	0	0	0	0	0	0	0

Therefore, for the communication of path, the urban objects of road, footpath, pedestrian, micromobility device and motor vehicle will be evaluated. For the communication of edge, the urban objects of road, pedestrian and micromobility device will be evaluated. For the communication of zone, footpath, pedestrian, micromobility device and motor vehicle will be evaluated. For the communication of node, micromobility device will be evaluated.

### 4.1.3 System Calibration 3

**Table 4.3: Calibration Table 3 - Experiment**

CALIBRATION 3															score
data type	artefact element parameter	shape				label				weight					
		u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3		
boolean (0 or 1)	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	
integer (= or > than 0)	count	0	0	0	0	0	0	0	0	0	0	0	0	0	
percentage	calculation	10%	20%	20%	0%	5%	10%	10%	0%	5%	10%	10%	0%		100%
result	amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0

For all four experiments, Calibration Table 3 will issue the following computational values for the statistical analysis and calculations of graphical elements. The shape geometry is allocated the value of 50%, label the value of 25% and weight the value of 25%. As shown in the table, each percentage value is further distributed. The point values will have point geometry  $U_0 = 10\%$ , with label  $V_0 = 5\%$  and weight  $W_0 = 5\%$ . The line values will have line geometry  $U_1 = 20\%$ , with label  $V_1 = 10\%$  and weight  $W_1 = 10\%$ . The plane values will have plane geometry  $U_2 = 20\%$ , with label  $V_2 = 10\%$  and weight  $W_2 = 10\%$ . Note that solid geometry  $U_3$  is given a zero, as the four artefacts being evaluated are in 2D format. Allocating a percentage value at this point to solid geometry will produce a bias in the evaluation of 2D artefacts. The impact of allocating percentage values is important to consider for the parameters of the evaluation. The proposed Calibration table 3 above for the following experiments show that the evaluation considers the shape geometry of point, line and plane to be more important and attracts a higher value of 50% than the graphical information attribution of the shape geometry, for label and weight, which are at 25% each. As well, the proposed value distribution shows that the evaluation puts more weight to lines and planes than the point geometry, hence the distribution of 10% to point and 20% to line and plane each reflect this evaluation requirement. Likewise, for label and weight, point label and weight each attract 5%, reflecting the hierarchy.

#### SYSTEM CALIBRATION NOTES

As shown above, the use of calibration tables allows the evaluation to be more intentional as the tables can limit and narrow down evaluation parameters. The calibration strategy enables the system to accommodate varied evaluation conditions and requirements, and limit bias at various points of the evaluation. As well, the results will reflect a more precise evaluation according to requirements.

## 4.2 EXPERIMENT 1

Experiment 1 is an evaluation of three artefacts. The first is Artefact 1. The second is Artefact 1 Test 1 and the third is Artefact 1 Test 2. At the conclusion of the experiment, a comparison of the three results will be presented.

### 4.2.1 Background Artefact 1

Experiment 1 examines a sample of a communication artefact used in an urban design project for micromobility infrastructure in Sydney.

Project 1 is a segment of the East West Pedestrian and Cycling link (Link) by Sydney Metro in response to the planning requirement for the delivery of the Southwest Sydney Metro infrastructure project. The segment is located within the Campsie town centre. Due to the lack of space within the Transport Asset Holding Entity (TAHE) rail corridor, the Link is proposed to run along Lilian Lane, owned and managed by the local government council (Council), and which is adjacent to the TAHE boundary. Lilian Lane runs parallel to the Metro rail as shown in Image 4.1 within the Transport Asset Holding Entity of NSW (TAHE)

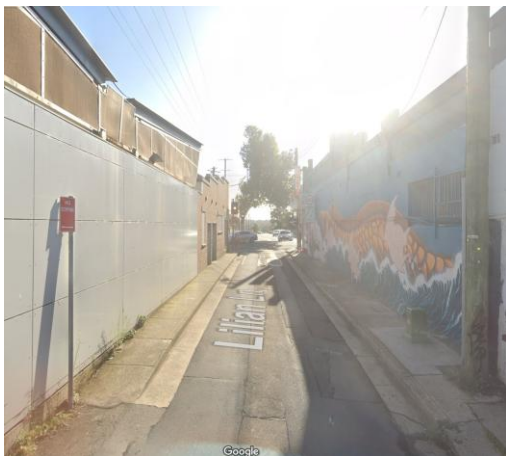


Figure 4.1: Project 1, 170-meter laneway highlighted in white.

As such the above image taken from *Nearmap* shows the relevant road, the boundaries and town centre context to illustrate the project's significance to road users, pedestrians and the local and business communities.



**Figure 4.2:** Google street view. Lilian Lane at the intersection of Beamish Street.



**Figure 4.3:** Google street view. Lilian Lane eastbound towards Beamish Street.

### Technical Constraints

Lilian Lane Campsie is a 170-meter laneway between Beamish Street and Dewar Street. It is a one-way, 6-meter-wide boundary to boundary road, inclusive of a single-vehicle

carriageway, and the verge area with gutter, kerb and footpath. The verge also contains other street elements such as lighting posts, electrical turrets and trees.



**Figure 4.4:** Google street view. Lilian Lane interfacing private driveways.



**Figure 4.5:** Google street view. Lilian Lane footpaths with electrical turrets, light posts and street trees.

### Conditions and Current Use

It is a key link to movement of pedestrians to and from the train station, and movement of vehicles to and from, through and within the general area, and waste management vehicles that service the properties along Lilian Lane. The north boundary of Lilian Lane is the Metro fence line with little available area within the TAHE corridor. The south boundary is lined with private properties of mixed commercial and residential multistorey buildings. The buildings have varying setbacks and Lilian Lane is also the only access point to most of these properties.

Pedestrian usage is high, as it is a secondary pedestrian link from Anzac Square to reach the train station. Private vehicles are also frequent and belong to the residents of the buildings, Heavy rigid vehicles are also constant throughout the week for waste management that service the properties. Lilian lane is a key link to movement of pedestrians to and from the train station,

and movement of vehicles to and from, through and within the general area, and waste management vehicles that service the properties along Lilian Lane. As the narrow roadway has little room for waste management location, this also results in garbage bins along the main roadway that is difficult to control and manage. This is typical in most Sydney town centres as they experience growth and higher densities. This condition exacerbates the risks posed to pedestrians and results in poor community outcomes along the laneway.

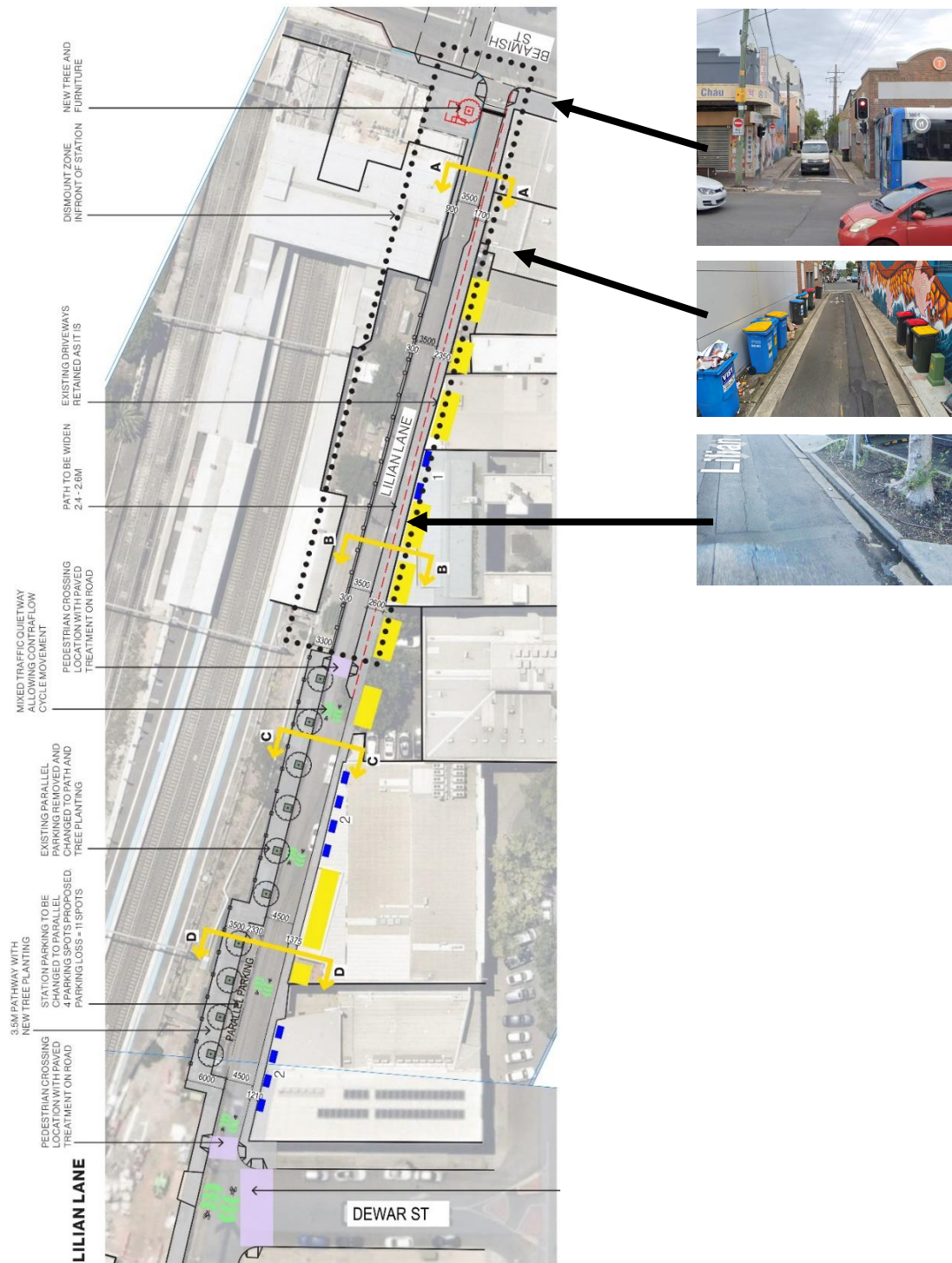


**Figure 4.6:** Google street view. Lilian Lane condition and use.

### Project Proposal

As part of the delivery of an east west pedestrian and cycling link, the urban design project proposes to improve these conditions and be able to safely share Lilian Lane with road users which include motor vehicles, micromobility devices which travel slower than motorised vehicles, and pedestrians at all hours, including peak hours. The stakeholders vary at different stages of the design development, and design implementation. Stakeholders from public and private sectors have varying priorities and objectives concerning this urban design project. They are a mix of domain and non-domain experts and professionals. Due to the nature of the project from a technical, social, environmental, economic and governmental perspective, this is considered a complex urban design project.

# ARTEFACT 1



**Figure 4.7:** Artefact 1.

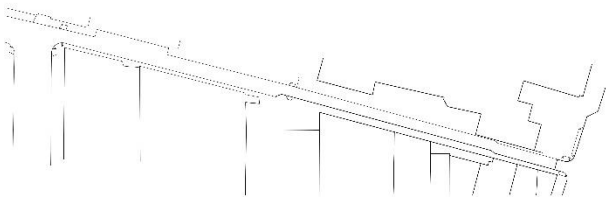
This is a sample of a communication artefact used in this urban design project which will be Artefact 1 and evaluated for Experiment 1.

#### 4.2.2 ARTEFACT 1 - LAYERS ANALYSIS

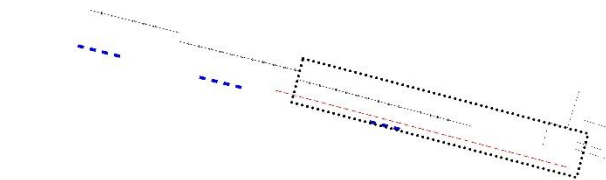
Artefact 1 is rationalised into layers of information. As such, Artefact 1 is considered to have the following data layers including the map underlay, the shape geometry of line, and the graphical information attributes of weight such as line weights and hatching or shading, and label such as annotations.



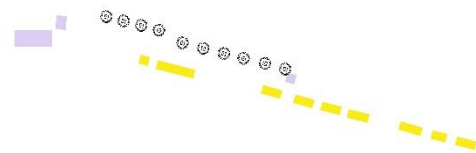
➤ MAP UNDERLAY



➤ LINES



➤ LINEWEIGHTS



➤ HATCHING/ SHADING



➤ ANNOTATIONS

**Figure 4.8:** Artefact 1 Shape Analysis.

## UNDERLAY ANALYSIS | GRAPHIC ALGEBRA:

SHAPE = Plane + Weight

ALGEBRA =  $U_2 + W_2$



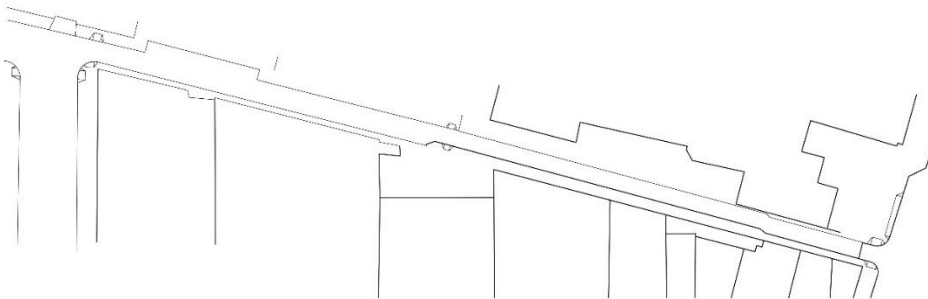
**Figure 4.9:** Artefact 1 Map Underlay.

As can be observed, the graphic is made up of a plane  $U_2$  geometry with an image that is considered as a graphical information attribute of weight  $W_2$ .

## LINES ANALYSIS | GRAPHIC ALGEBRA:

SHAPE = LINE

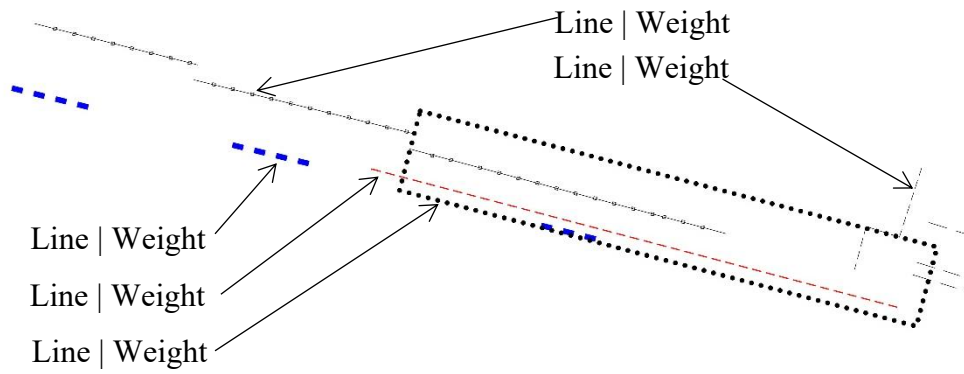
ALGEBRA =  $U_{12}$



**Figure 4.10:** Artefact 1 Line Layer.

As can be observed, this layer of information is made up of a line  $U_1$  geometry that is arranged and laid out onto a flat 2D surface. This means the line network is on a 2-dimensional plane, hence the geometric algebra is  $U_{12}$ , as explored in Chapter 1.

LINEWEIGHTS ANALYSIS | GRAPHIC WEIGHTS



**Figure 4.11:**Artefact 1 Line Weights.

GRAPHIC WEIGHTS & ALGEBRA:

**Table 4.4:** Artefact 1 Line Analysis

	SHAPE: LINE $U_1$	WEIGHTS	ALGEBRA
1		Line type, thickness and colour	$U_{11} W_3$
2		Line type	$U_{11} W_1$
3		Line type and thickness	$U_{11} W_2$
4		Line type, thickness and colour	$U_{11} W_3$
5		Line type	$U_{12} W_1$

As shown in Figure 4.12, this layer of information presents various weight graphical information attributes for the line  $U_1$  geometry. As example, it identifies that item 1 which is fundamentally a simple straight line  $U_1$  geometry, has been enhanced with a line type of broken line, a thickness and a colour attribute of blue. This gives the weight value and algebra for weight of  $W_3$ . Hence, when combined the graphic for item 1 has the algebra of  $U_{11} W_3$ .

HATCHING SHADING ANALYSIS | GRAPHIC WEIGHTS

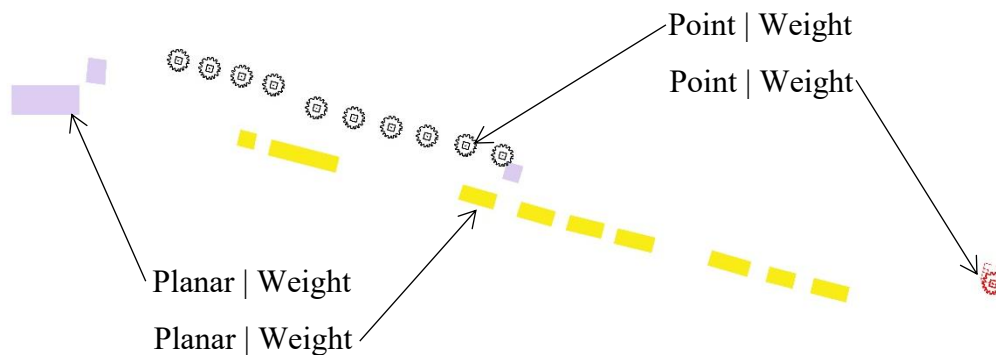


Figure 4.12: Artefact 1 point and plane weights.

GRAPHIC POINT AND PLANE WEIGHTS ALGEBRA

Table 4.5: Artefact 1 Point and Plane Analysis

	SHAPE: POINT	WEIGHTS	ALGEBRA
1		Type of point, thickness	$U_{00} W_2$
2		Type of point, thickness, and colour	$U_{00} W_3$
	SHAPE: PLANE   WEIGHTS		ALGEBRA
1		Colour	$U_{22} W_1$
2		Colour	$U_{22} W_1$

In Figure 4.13, this layer of information presents various weight graphical information attributes for the point  $U_0$  geometry and for plane  $U_2$  geometry. As example, it identifies that item 1 for point which is fundamentally a simple point  $U_0$  geometry, has been enhanced with a type of point and a thickness, hence the geometry is  $W_2$ . Similarly, for plane  $U_2$  geometry, it has been enhanced with a graphical information attribute of weight such as colour. Hence the geometry is  $W_1$ . This examination is carried out as part of the statistical analysis for each graphical element present in the artefact.


### ANNOTATIONS ANALYSIS | GRAPHIC LABELS



**Figure 4.13:** Artefact 1 plane labels.

## GRAPHIC LABELS ALGEBRA

**Table 4.6: Artefact 1 point and plane weights**







	SHAPE: PLANE	LABEL	ALGEBRA
1		on plan	$U_{22} V_1$
2	DEWAR ST	on plan	$U_{11} V_1$
3	LILIAN LANE	on plan	$U_{11} V_1$
4	BEAMISH ST	on plan	$U_{22} V_1$

As can be observed, this layer of information presents various label graphical information attributes for the plane  $U_2$  geometry. As example, it identifies that item 1 for the underlying plane has been enhanced with a graphical information attribute of label such as symbol and location text.

These collected statistics analysis data will be used as reference for the system analysis for Artefact 1 and the system evaluation.

### 4.2.3 ARTEFACT 1 - STATISTICAL ANALYSIS

This critical analysis table also shows the initial geometries recorded and contained in the artefact and examines their generative transformation values when translating geometric structures. These translations will be used as reference for Test 1 and Test 2.

		
<b>Road straight paths</b>	<b>Road straight paths and nodes</b>	<b>Road curved and straight paths</b>
U1 2 (line on 2D space)	U1 2 (line on 2D space) U0 2 (point on 2D space)	U1 2 (line on 2D space)
		
<b>Road weighted paths</b>	<b>Road weighted and labelled paths</b>	<b>Cars movement space boundaries</b>
U1 2 (line on 2D space) W1 2 (shade/colour on 1D shape)	U1 2 (line/curve on 2D space) V0 1 (point/symbol on 1D shape) W1 2 (shade/colour on 1D shape)	U1 2 (line, arc) V0 1 (arrow) W1 2 (red)



**Cars movement**

**weighted space**

U1 2 (line, arc)

V0 1 (arrow)

W1 2 (red)

W2 2 (purple)



**Road boundaries**

U1 2 (line, arc)

V0 1 (arrow)

W1 2 (red)

W2 2 (purple)



**Road weighted space**

U1 2 (line, arc on 2D space)

U2 2 (surface on 2D space)

V0 1 (point/symbol on 1D shape)

W1 2 (colour/thickness on 1D shape)

W2 2 (colour/hatch on 2D shape)



**Kerb boundary**

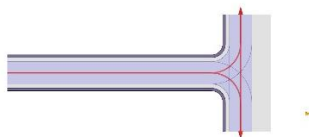
U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red)

W2 2 (purple, grey)



**Kerb/gutter surface**

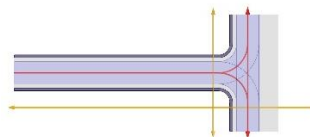
U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red)

W2 2 (purple, grey, dark grey)



**Pedestrian movement**

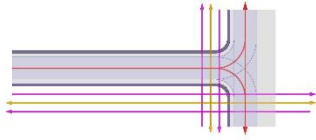
U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red, yellow)

W2 2 (purple, grey, dark grey)



**Pedestrian bi-direction**

**movement**

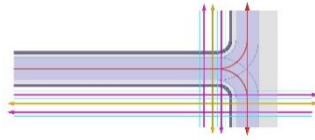
U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red, yellow,  
magenta)

W2 2 (purple, grey, dark  
grey)



**Pedestrian bi-direction**

**boundary**

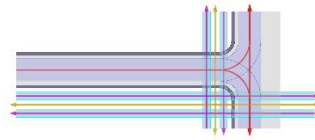
U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red, yellow,  
magenta, cyan)

W2 2 (purple, grey, dark  
grey)



**Pedestrian bi-direction**

**movement space**

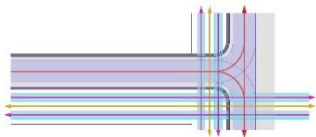
U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red, yellow,  
magenta, cyan)

W2 2 (purple, grey, dark  
grey, cyan)



**Pedestrian footprint**

**boundary**

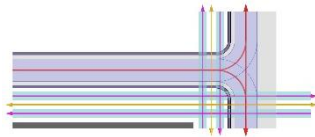
U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red, yellow,  
magenta, cyan, dark grey)

W2 2 (purple, grey, dark  
grey, cyan)



**Building footprint**

**surface**

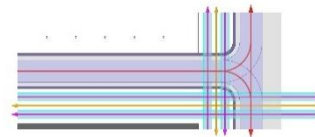
U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red, yellow,  
magenta, cyan, dark grey)

W2 2 (grey, cyan, yellow,  
black)



**Tree location**

U0 1 (Tree line location)

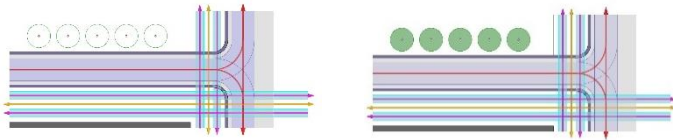
U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red, yellow,  
magenta, cyan, dark grey)

W2 2 (grey, cyan, yellow,  
black)



<b>Tree diameter</b>	<b>Tree canopy</b>
U0 1 (Tree line location)	U0 1 (Tree line location)
U1 2 (line, arc, circle)	U1 2 (line, arc, circle)
U2 2 (surface)	U2 2 (surface)
V0 1 (arrow)	V0 1 (arrow)
W1 2 (red, yellow, magenta, cyan, dark grey, green)	W1 2 (red, yellow, magenta, cyan, dark grey, green)
W2 2 (grey, cyan, yellow, black)	W2 2 (grey, cyan, yellow, black, green)

**Figure 4.14:** Artefact 1 geometric transformation analysis.

As shown in Figure 4.14, the same geometries can be manipulated and adjusted to produce variations of graphic representations and geometric algebra. As can be observed the graphics look very similar, however slight changes can produce or deduct layers of information.

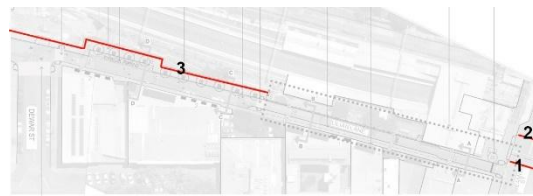
In assessing the graphic representations in the table, a path, which is described as a channel or route for travelling along, for communication purposes will need to be conveyed distinctly from edge. This means that unless a line is in the middle of the road and is instead located at the boundary of the carriageway, then the line is considered an edge. However, if a line has direction labels such as arrows, regardless of whether it is located in the middle of the road or at the edge, it signifies that it is a path for travelling along. This will be typically considered across all four experiments.

This is for the purpose of the evaluation and to make a distinction from a line that may be used to represent edge, as movement information and understanding is considered critical in this urban design project. Two parallel lines as edges that may represent kerbs, cannot be assumed that in between the kerb is a path for travelling along.

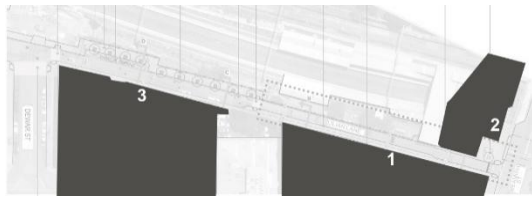
Based on these assumptions and conditions, Artefact 1's statistical analysis are in the table below. The shape geometry counts are shown below for easy identification of the geometry the count is referring to.



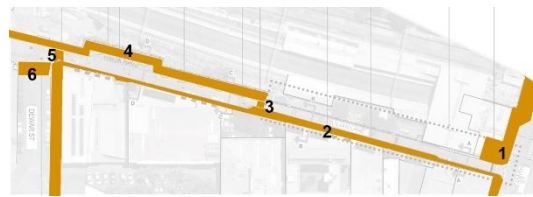
road-edge:  $U1=4, W1=1$



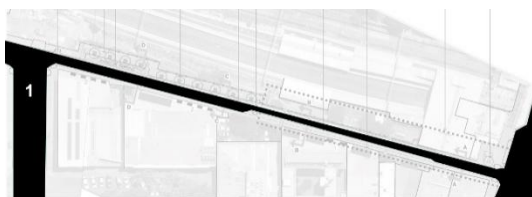
pedestrian-edge (line):  $U1=3, W=1$



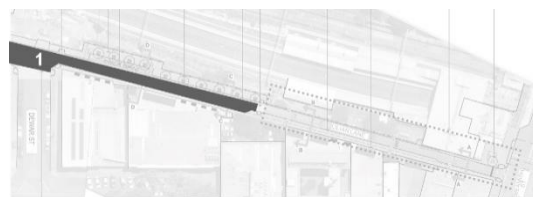
pedestrian-edge (plane):  $U2=3, W2=3$



pedestrian-zone:  $U2=6, V2=4, W2=1$



motor vehicle-zone:  $U2=1, V2=3, W2=1$



micromob-zone:  $U2=1, V2=20, W2=1$



micromobility-node:  $U2=1, W2=2$

**Figure 4.15:** Artefact 1 shape geometry count illustration.

## 4.2.4 ARTEFACT 1 - ARTEFACT ANALYSIS & EVALUATION

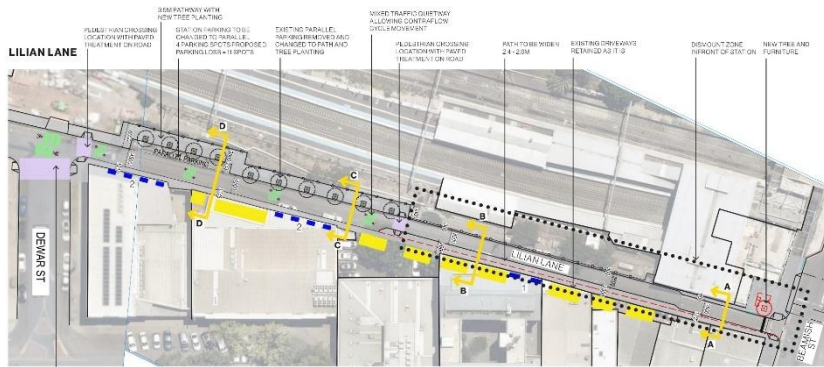


Figure 4.16: Artefact 1.

Table 4.7: Artefact 1 geometry count

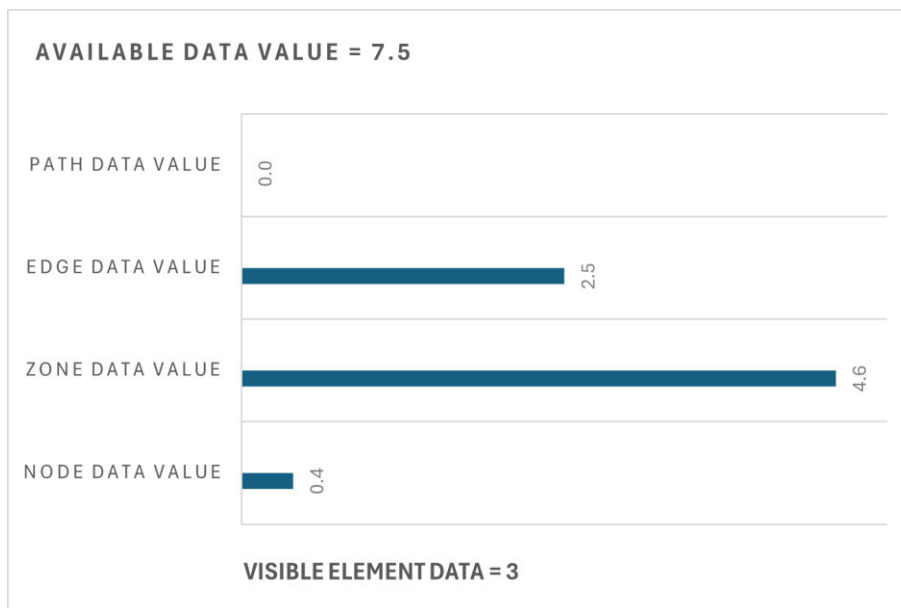
	Shape	Label	Weight
<i>Path</i>	0	0	0
<i>Edge-road</i>	U1=4	0	W1=1
<i>Edge-pedestrian</i>	U1=3, U2=3	0	W1=1, W2=3
<i>Edge-micro device</i>	0	0	0
<i>Zone-pedestrian</i>	U2=6	V2=4	W2=1
<i>Zone-motor vehicle</i>	U2=1	V2=3	W2=1
<i>Zone-micro device</i>	U2=1	V2=20	W2=1
<i>Node-micro device</i>	U2=1	0	W2=2

## ARTEFACT 1 SYSTEM ANALYSIS:

Based on the graphical layers analysis, the system calculated the graphical statistics and calculated the values based on Calibration table 3

The Available Data Value is 7.5 which is the total value of the artefact based on the visible urban elements combined. The system also calculated the number of urban elements in the artefact. Artefact 1 has a total of 3 elements edge, zone and node (Visible Element Data). The analysis for Artefact 1 in Experiment 1 shown in the tables in Sub-Section 4.3.8 and the summary breakdown of the data values are shown below:

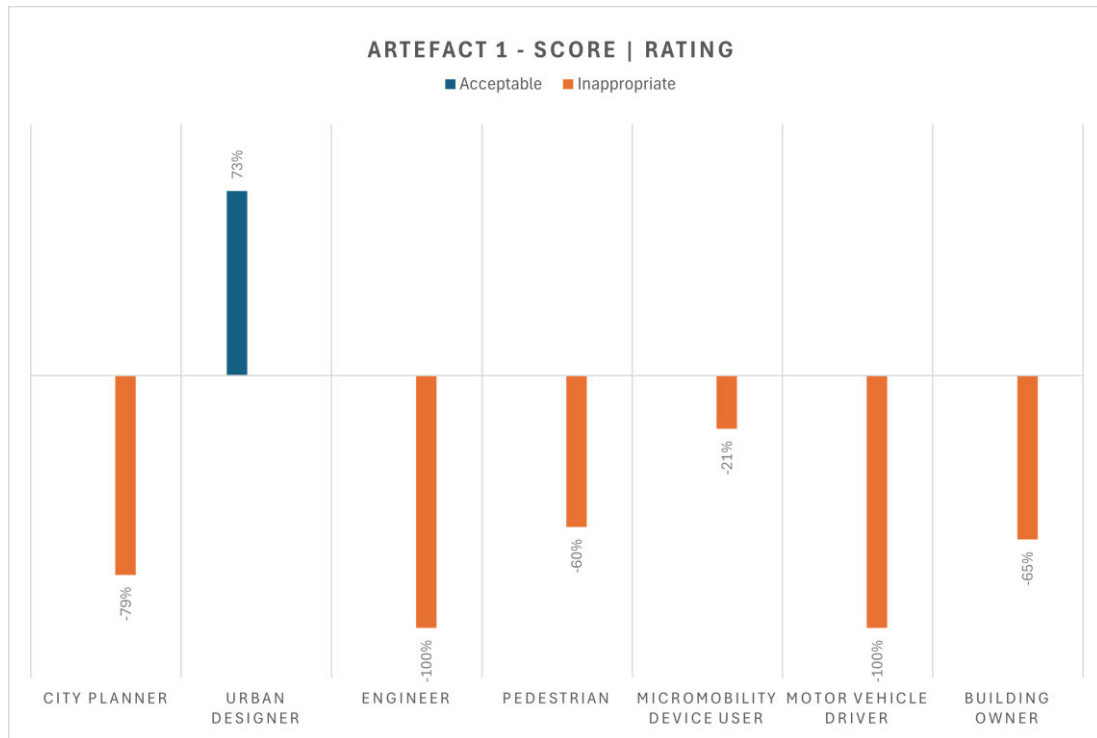
**Table 4.8: Artefact 1 Analysis Summary**



As noted on the assumptions discussed earlier, the path urban element is not featured in Artefact 1. Hence, the path data value is zero. As well the urban elements of landmark and district have been turned off to avoid bias, as discussed earlier. These data values are automated inputs to the evaluation phase 2 of the system.

## ARTEFACT 1 SYSTEM EVALUATION:

**Table 4.9: Artefact 1 Evaluation Summary**



The chart above shows the summary of artefact evaluation against stakeholders' requirements set out in Calibration Table 1. Based on the given artefact and the parameters set out in Calibration Table 2, the artefact was measured with a Score and a Rating. The blue bar means the artefact is acceptable to Urban Designer stakeholder, whilst the orange bars mean the artefact is inappropriate to City Planner, Engineer, Pedestrian, Micromobility Device User, Motor Vehicle Driver and Building Owner stakeholders.

As such, based on the Available Data Value = 7.5, and the Visible Element Data = 3 of Artefact 1, the Result shows the artefact's score and rating for each stakeholder in the table shown in Sub-Section 4.2.8.

#### 4.2.5 TEST 1 – Artefact 1

Test 1 Artefact 1 presents a variation to the graphical data in Artefact 1 and is customised to improve its performance for the *urban designer* stakeholder. The test artefact is not a precise replica but a rendition of Artefact 1 to demonstrate the graphic transformation of geometry based on the original artefact geometry.

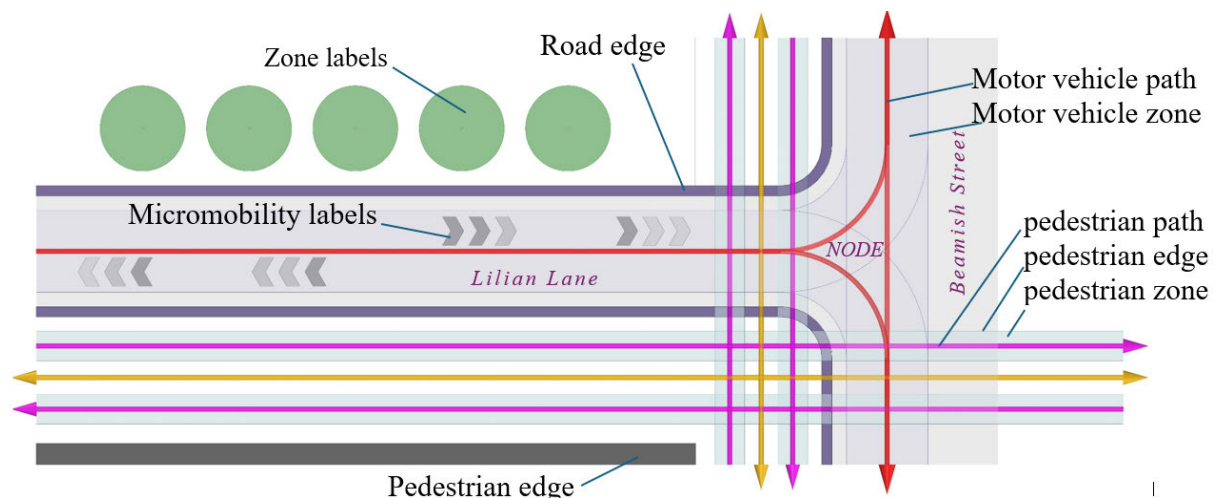


Figure 4.17: Test 1 Artefact 1.

According to Calibration table 1, urban designer stakeholder requires information on path, edge, zone and node. With the view of improving the performance of Artefact 1 for the urban designer stakeholder for the purpose of testing the system, Test 1 Artefact 1 shows an increase in count for the relevant urban elements.

In this case, as path is lacking in Artefact 1, the path element is highly featured in Test 1 Artefact 1. Observe the lines with arrows. They represent path as the lines are not edges as discussed in the conditions earlier. E.g. The red lines are a road path with arrows. This has the geometry algebra of  $U1 = 3$ ,  $V1 = 2$  and  $W2 = 2$ . The line geometry has three, the two arrowheads represent 2 labels and weight is 2 for thickness and colour.

**Table 4.10: Test 1 Artefact 1 geometry count**

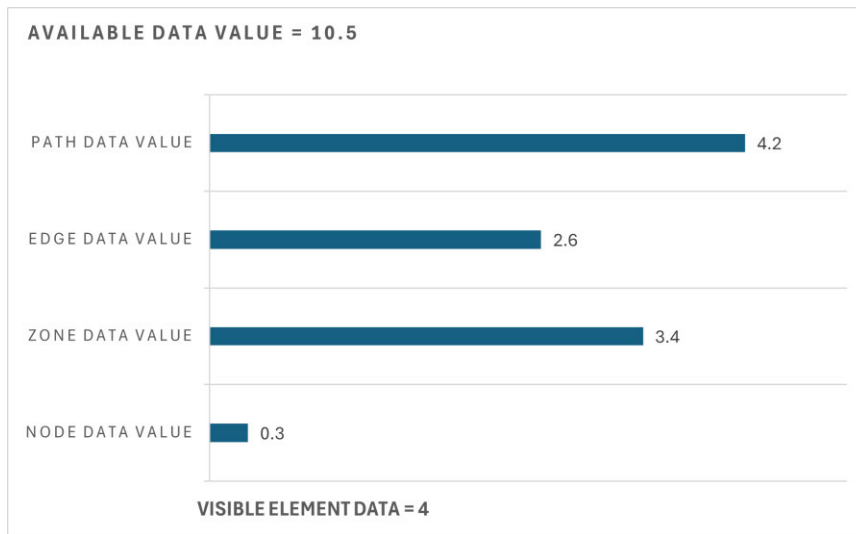
	Shape	Label	Weight
<i>Path-road</i>	U1=3	V1=2	W1=2
<i>Path-motor vehicle</i>	0	0	0
<i>Path-pedestrian</i>	U1=6	V1=10	W1=3
<i>Path-micro device</i>	U2=1	V2=4	W2=1
<i>Edge-road</i>	U1=2	0	W1=2
<i>Edge-pedestrian</i>	U1=8, U2=1	0	W1=1, W=1
<i>Edge-micro device</i>	0	0	0
<i>Zone-pedestrian</i>	U2=5	V2=5	W2=2
<i>Zone-motor vehicle</i>	U2=3	V2=2	W2=2
<i>Zone-micro device</i>	U2=1	V2=4	W2=1
<i>Node-micro device</i>	U2=1	V2=1	0

**TEST 1 ARTEFACT 1 SYSTEM ANALYSIS:**

The above table shows the geometry count for Test 1 Artefact 1. The result summary of the analysis for Test 1 Artefact 1 is shown below which shows a great increase in path and slight increase in edge data values compared to Artefact 1 analysis. Zone and node data value decreased. The analysis table is in Sub-Section 4.2.8.

The System Analysis for the Test 1-Artefact 1 in Experiment 1 shows:

**Table 4.11: Test 1 Artefact 1 Analysis Summary**



TEST 1 ARTEFACT 2 SYSTEM EVALUATION:

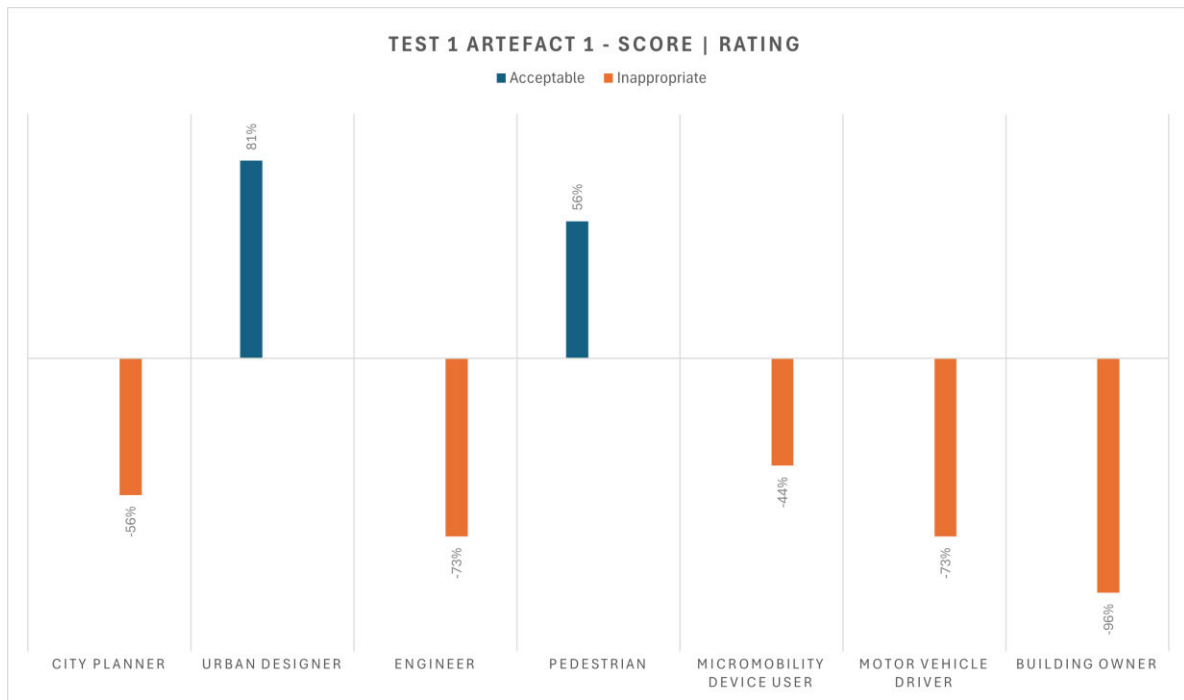
The System Evaluation for the Test 1 Artefact 1 in Experiment 1:

The system evaluated the artefact's statistical data analysis against the requirements set out for individual stakeholders. The system produced an autogenerated result as shown in evaluation table in Sub-Section 4.2.8 for Test 1 Artefact 1 Evaluation.

The table shows the result of the evaluation for Test 1 Artefact 1 which shows a slight improvement on the performance of the artefact for urban designer with a score increase from 73% to 81% Acceptability.

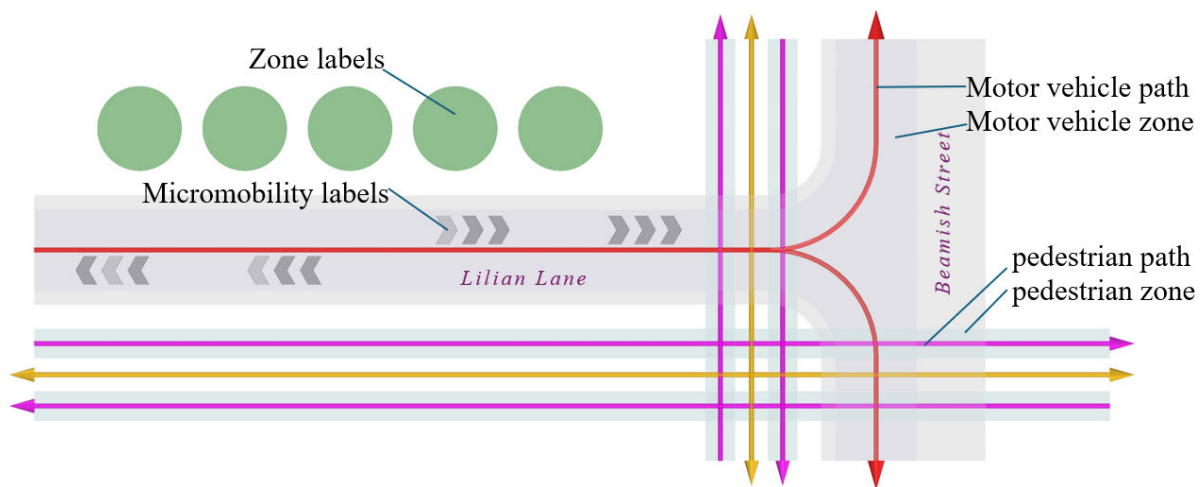
Based on the Available Data Value = 10.5, and the Visible Element Data = 4 of Test 1-Artefact 1, the summary of the Result is shown in the chart below for the artefact's score and rating for each stakeholder:

**Table 4.12: Test 1 Artefact 1 Evaluation Summary**



#### 4.2.6 TEST 2 – Artefact 1

Test 2 Artefact 1 also presents another variation to the graphical data in Artefact 1 and is customised to improve its performance for the micromobility device user stakeholder. As a rendition of Artefact 1 the graphic transformation of geometry will be adjusted to meet the requirements for the micromobility device user set out in Calibration table 1.



**Figure 4.18:** Test 2-Artefact 1.

According to Calibration table 1, micromobility device user stakeholder requires information on just two urban elements, path and zone. With the view of improving the performance of Test 2 Artefact 1 for the micromobility device user stakeholder for the purpose of further testing the system, Test 2 Artefact 1 shows a decrease on the urban elements featured in the artefact.

In this case, as path is lacking in Artefact 1 but is required by the micromobility device user, and both edge and node are not required but are present, Test 2 Artefact 1 is adjusted accordingly showing path is featured, whilst all information on edges such as kerbs and boundaries have been removed as well as node.

**Table 4.13: Test 1 Artefact 1 geometry count**

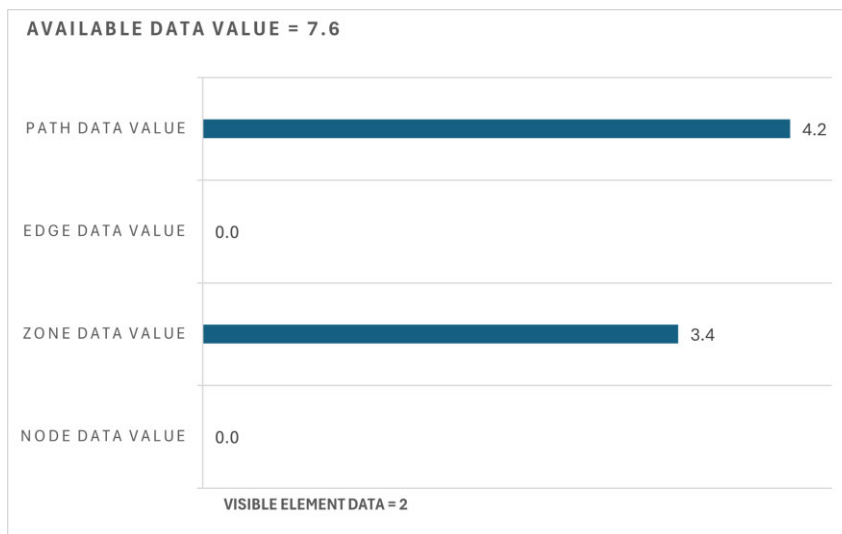
	Shape	Label	Weight
<i>Path-road</i>	U1=2	V1=2	W1=2
<i>Path-motor vehicle</i>	0	0	0
<i>Path-pedestrian</i>	U1=6	V1=10	W1=3
<i>Path-micro device</i>	U2=1	V2=4	W2=1
<i>Edge</i>	0	0	0
<i>Zone-pedestrian</i>	U2=5	V2=5	W2=2
<i>Zone-motor vehicle</i>	U2=3	V2=2	W2=2
<i>Zone-micro device</i>	U2=1	V2=4	W2=1
<i>Node-micro device</i>	0	0	0

**TEST 2 ARTEFACT 1 SYSTEM ANALYSIS:**

Although the total Available Data Value is only 0.1 more compared to Artefact 1, the number of Visible Element Data is reduced to only two, whilst Artefact 1 has 3.

The System Analysis for the Test 2 Artefact 1 in Experiment 1 shows:

**Table 4.14: Test 2 Artefact 1 Analysis Summary**



#### TEST 2 ARTEFACT 1 SYSTEM EVALUATION:

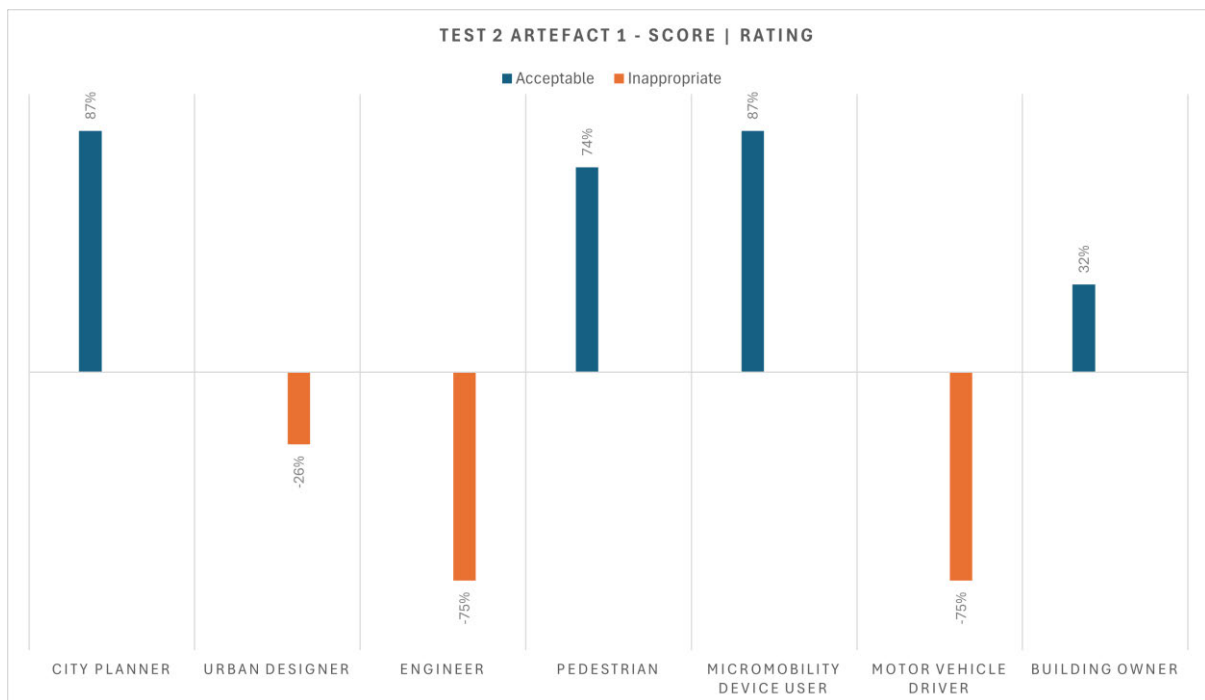
##### The System Evaluation for the Test 2 Artefact 1 in Experiment 1:

The system evaluated the artefact's statistical data analysis against the requirements set out for individual stakeholders. The system produced an autogenerated result as shown in the evaluation table in Sub-Section 4.2.8 for Test 2-Artefact 1 Evaluation.

The table shows the result of the evaluation for Test 2 Artefact 1 which results in a great improvement on the performance of the artefact for micromobility device user stakeholder with a score increase from 21% Inappropriate to 87% Acceptable.

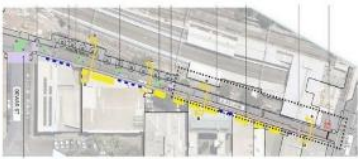
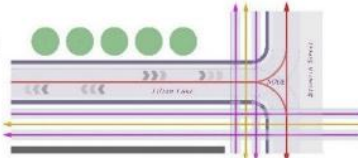
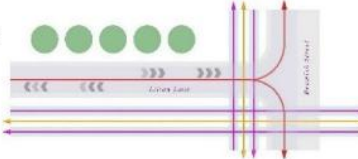
Based on the Available Data Value = 7.6, and the Visible Element Data = 2 of Test 2-Artefact 1, the summary of the Result is shown in the chart below for the artefact's score and rating for each stakeholder:

**Table 4.15: Test 2 Artefact 1 Evaluation Summary**



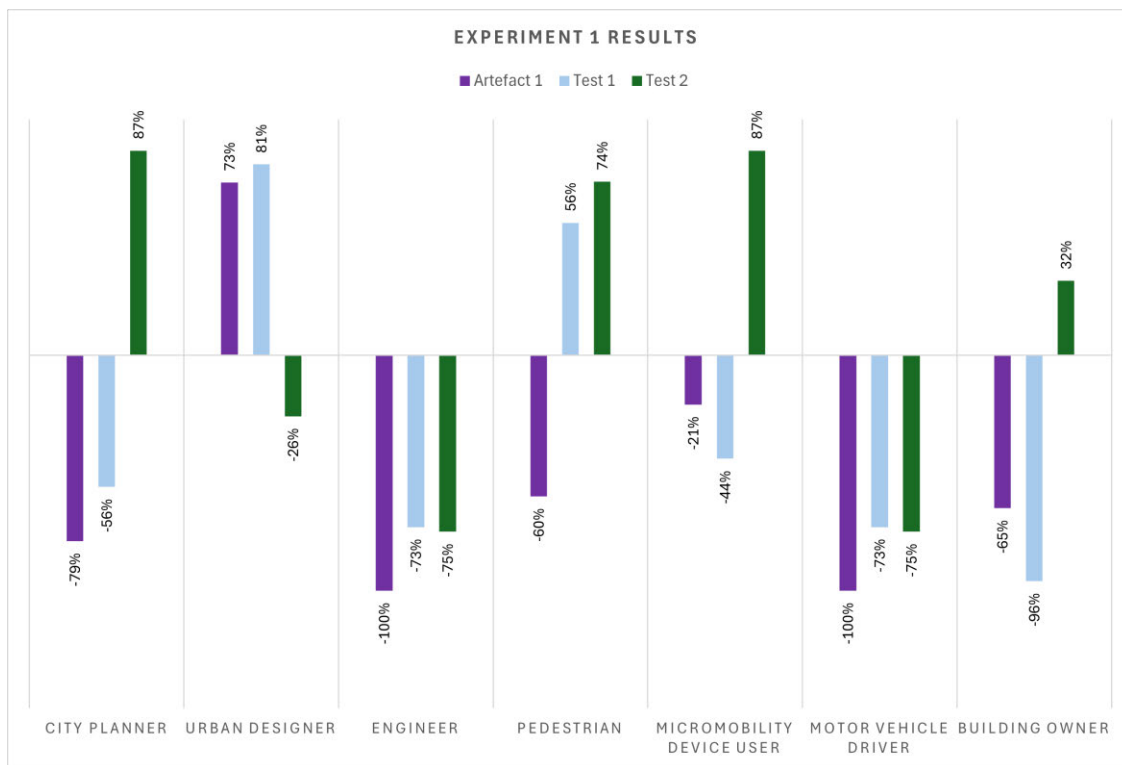
## 4.2.7 PERFORMANCE RESULTS

This Sub-Section shows the results for Experiment 1. The results for artefact graphic comparison and the score and ranking for each for *urban designer* and for *micromobility device user* based on the parameters set out in Calibration tables 1 and 2 and the computation set out in Calibration table 3 are shown below. As well the overall results summary for Experiment 1 is summarised in the chart below and the overall performance comparison are set out below to illustrate the percentage data value and the percentage data failure for all three artefacts in Experiment 1.

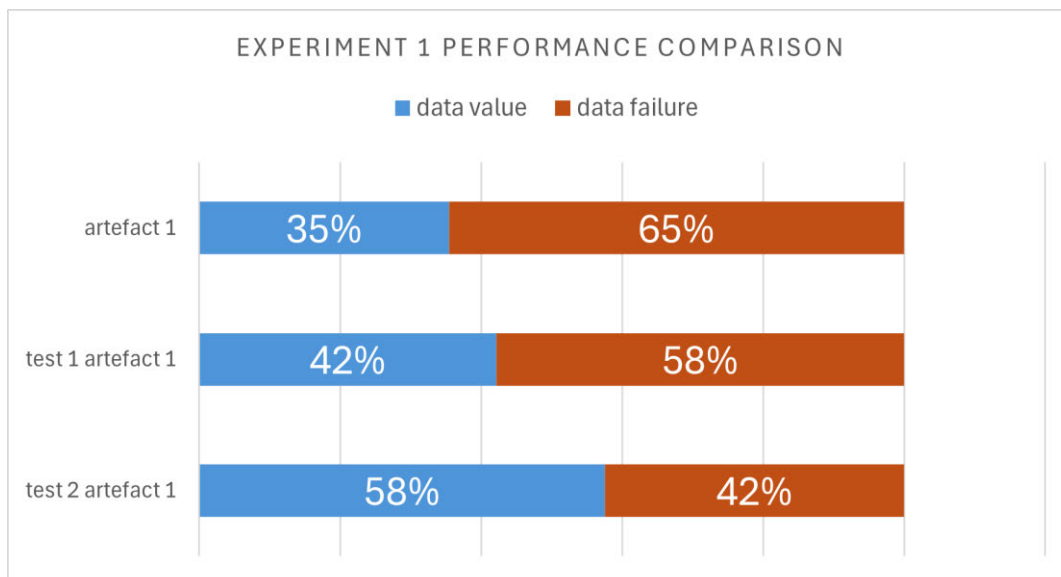
EXPERIMENT 1		urban designer	micromobility device user
ARTEFACT 1		85% Acceptable	56% Inappropriate
EST 1 ARTEFACT 1		87% <b>Acceptable</b>	63% Inappropriate
EST 2 ARTEFACT 1		26% Inappropriate	91% <b>Acceptable</b>

**Figure 4.19:** Experiment 1 Results Comparison

**Table 4.16: Experiment 1 Results Summary**



**Table 4.17: Experiment 1 Artefacts Performance Results**



## 4.2.8 ANALYSIS & EVALUATION TABLES

### ARTEFACT 1 ANALYSIS & EVALUATION

Table 4.18: Artefact 1 Analysis

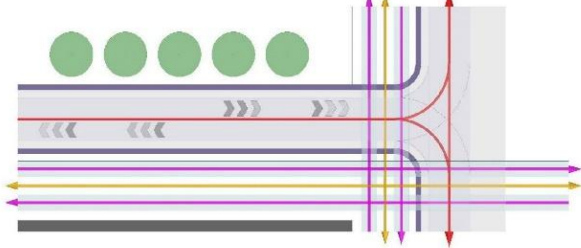
			ANALYSIS												Sum	
			shape				label				weight					
urban object	urban element	parameter	Artefact #1				Artefact #1				Artefact #1				Sum	
			u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3		
			point	line/ curve	plane	solid	text/ number/ symbol	line/ curve	plane	solid	point area	thickn ess/ colour	hatch/ colour	hatch/ colour		
0	road	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	
0	motor vehicle	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	
0	pedestrian	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	
0	micromobility d	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	
0	0															0.0
0.0 PATH DATA VALUE																
1	road	edge	visibility	0	1	0	0	0	0	0	0	0	1	0	0	0.9
			count	0	4	0	0	0	0	0	0	0	1	0	0	
			amount	0	0.8	0	0	0	0	0	0	0	0.1	0	0	
1	pedestrian	edge	visibility	0	1	1	0	0	0	0	0	0	1	1	0	1.6
			count	0	3	3	0	0	0	0	0	0	1	3	0	
			amount	0	0.6	0.6	0	0	0	0	0	0	0.1	0.3	0	
0	micromobility d	edge	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	
1	2															0.0
2.5 EDGE DATA VALUE																
1	pedestrian	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	1.7
			count	0	0	6	0	0	0	4	0	0	0	1	0	
			amount	0	0	1.2	0	0	0	0.4	0	0	0	0.1	0	
1	motor vehicle	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	0.6
			count	0	0	1	0	0	0	3	0	0	0	1	0	
			amount	0	0	0.2	0	0	0	0.3	0	0	0	0.1	0	
1	micromobility d	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	2.3
			count	0	0	1	0	0	0	20	0	0	0	1	0	
			amount	0	0	0.2	0	0	0	2	0	0	0	0.1	0	
1	3															2.3
4.6 ZONE DATA VALUE																
1	micromobility d	node	visibility	0	0	1	0	0	0	0	0	0	0	1	0	0.4
			count	0	0	1	0	0	0	0	0	0	0	2	0	
			amount	0	0	0.2	0	0	0	0	0	0	0	0.2	0	
1	1															0.4
0.4 NODE DATA VALUE																
0	micromobility d	landmark	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0
			count	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	
0	0															0
0.0 LANDMARK DATA VALUE																
0	micromobility d	district	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0
			count	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	
0	0															0
0.0 DISTRICT DATA VALUE																
3	VISIBLE ELEMENT DATA														7.5	
4	REQUIRED ANALYSED DATA														AVAILABLE DATA VALUE (ADV)	

**Table 4.19: Artefact 1 Evaluation**

EVALUATION										
System calculates:										
urban object-urban element	urban element visibility	city planner	urban designer	engineer	pedestrian	micromobility device user	motor vehicle driver	building owner		
road-path	0	-1	-1	-1	-1	-1	-1	0		
motor vehicle-path	0	-1	-1	-1	-1	-1	-1	0		
pedestrian-path	0	-1	-1	-1	-1	-1	-1	0		
micromobility device-path	0	-1	-1	-1	-1	-1	-1	0		
	DATA PENALTY	-1	-1	-1	-1	-1	-1	-1	0	0
	PATH DATA VALUE LESS PENALTY	-1	-1	-1	-1	-1	-1	-1	0	0
	ELEMENT PENALTY	-1	-1	-1	-1	-1	-1	-1	0	0
road-edge	1	-1	0	0	-1	-1	0	-1		
pedestrian-edge	1	-1	0	0	-1	-1	0	-1		
micromobility device-edge	0	0	-1	-1	0	0	-1	0		
	DATA PENALTY	-1	-1	-1	-2	-2	-1	-2	-2	-1
	EDGE DATA VALUE LESS PENALTY	-1	-1	-1	-2	-2	-1	-1	-2	-1
	ELEMENT PENALTY	-1	0	0	-1	-1	0	0	-1	-1
pedestrian-zone	1	0	0	-1	0	0	-1	0		
motor vehicle-zone	1	0	0	-1	0	0	-1	0		
micromobility device-zone	1	0	0	-1	0	0	-1	0		
	DATA PENALTY	0	0	-3	0	0	-3	0	0	4.6
	ZONE DATA VALUE LESS PENALTY	0	0	-3	0	0	-3	0	0	4.6
	ELEMENT PENALTY	0	0	-1	0	0	-1	0	0	4.6
micromobility device-node	1	-1	0	-1	0	-1	-1	-1		
	DATA PENALTY	-1	0	-1	0	-1	-1	-1	-1	-1
	NODE DATA VALUE LESS PENALTY	-1	0	-1	0	-1	-1	-1	-1	-1
	ELEMENT PENALTY	-1	0	-1	0	-1	-1	-1	-1	-1
micromobility device-landmark	0	0	0	0	0	0	0	0		
	DATA PENALTY	0	0	0	0	0	0	0	0	0
	LANDMARK DATA VALUE LESS PENALTY	0	0	0	0	0	0	0	0	0
	ELEMENT PENALTY	0	0	0	0	0	0	0	0	0
micromobility device-district	0	0	0	0	0	0	0	0		
	DATA PENALTY	0	0	0	0	0	0	0	0	0
	DISTRICT DATA VALUE LESS PENALTY	0	0	0	0	0	0	0	0	0
	ELEMENT PENALTY	0	0	0	0	0	0	0	0	0
<b>SCORING</b>										
<b>STAKEHOLDER DATA VALUE</b>		1.6	5.5	-1.5	3	1.6	-1.5	2.6		
<b>VALUABLE DATA</b>		21%	73%	-20%	40%	21%	-20%	35%		
<b>RATING</b>										
<b>REQUIRED ELEMENT DATA</b>		2	4	2	3	2	2	1		
<b>TOTAL ELEMENT PENALTY</b>		-3	-1	-3	-2	-3	-3	-2		
<b>ELEMENT DATA FAILURE</b>		75%	25%	75%	50%	75%	75%	50%		
<b>Rated As:</b>		Inappropriate	Acceptable	Inappropriate	Inappropriate	Inappropriate	Inappropriate	Inappropriate		
<b>RESULT</b>		79%	73%	100%	60%	21%	100%	65%		
		Inappropriate	Acceptable	Inappropriate	Inappropriate	Inappropriate	Inappropriate	Inappropriate		

# TEST 1 ARTEFACT 1 ANALYSIS & EVALUATION

**Table 4.20: Test 1 Artefact 1 Analysis**



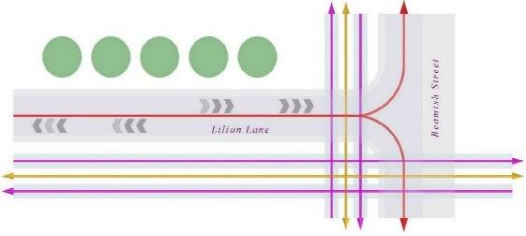
urban object	urban element	parameter	shape				ANALYSIS				Test 1 Artefact #1				Sum	
			point	line/curve	plane	solid	text/number/symbol	line/curve	plane	solid	point area	thickn ess/colour	hatch/colour	hatch/colour		
			u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3		
1	road	path	visibility	0	1	0	0	0	1	0	0	0	1	0	0	1
		count	0	3	0	0	0	2	0	0	0	2	0	0		
		amount	0	0.6	0	0	0	0.2	0	0	0	0.2	0	0		
0	motor vehicle	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0		
		amount	0	0	0	0	0	0	0	0	0	0	0	0		
1	pedestrian	path	visibility	0	1	0	0	0	1	0	0	0	1	0	0	2.5
		count	0	6	0	0	0	10	0	0	0	3	0	0		
		amount	0	1.2	0	0	0	1	0	0	0	0.3	0	0		
1	micromobility device	path	visibility	0	0	1	0	0	0	1	0	0	0	1	0	0.7
		count	0	0	1	0	0	0	4	0	0	0	1	0		
		amount	0	0	0.2	0	0	0	0.4	0	0	0	0.1	0		
1	3															4.2 PATH DATA VALUE
1	road	edge	visibility	0	1	0	0	0	0	0	0	0	1	0	0	0.6
		count	0	2	0	0	0	0	0	0	0	2	0	0		
		amount	0	0.4	0	0	0	0	0	0	0	0.2	0	0		
1	pedestrian	edge	visibility	0	1	1	0	0	0	0	0	0	1	1	0	2
		count	0	8	1	0	0	0	0	0	0	1	1	0		
		amount	0	1.6	0.2	0	0	0	0	0	0	0.1	0.1	0		
0	micromobility device	edge	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0		
		amount	0	0	0	0	0	0	0	0	0	0	0	0		
1	2															2.6 EDGE DATA VALUE
1	pedestrian	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	1.7
		count	0	0	5	0	0	0	5	0	0	0	2	0		
		amount	0	0	1	0	0	0	0.5	0	0	0	0.2	0		
1	motor vehicle	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	1
		count	0	0	3	0	0	0	2	0	0	0	2	0		
		amount	0	0	0.6	0	0	0	0.2	0	0	0	0.2	0		
1	micromobility device	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	0.7
		count	0	0	1	0	0	0	4	0	0	0	1	0		
		amount	0	0	0.2	0	0	0	0.4	0	0	0	0.1	0		
1	3															3.4 ZONEDATA VALUE
1	micromobility device	node	visibility	0	0	1	0	0	0	1	0	0	0	0	0	0.3
		count	0	0	1	0	0	0	1	0	0	0	0	0		
		amount	0	0	0.2	0	0	0	0.1	0	0	0	0	0		
1	1															0.3 NODE DATA VALUE
0	micromobility device	landmark	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0		
		amount	0	0	0	0	0	0	0	0	0	0	0	0		
0	0															0.0 LANDMARK DATA VALUE
0	micromobility device	district	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0		
		amount	0	0	0	0	0	0	0	0	0	0	0	0		
0	0															0.0 DISTRICT DATA VALUE
4	VISIBLE ELEMENT DATA														10.5	AVAILABLE DATA VALUE
4	REQUIRED ANALYSED DATA															

**Table 4.21: Test 1 Artefact 1 Evaluation**

EVALUATION										
System calculates:										
urban object-urban element	urban element visibility	city planner	urban designer	engineer	pedestrian	micromobility device user	motor vehicle driver	building owner		
road-path	1	0	0	0	0	0	0	-1		
motor vehicle-path	0	-1	-1	-1	-1	-1	-1	0		
pedestrian-path	1	0	0	0	0	0	0	-1		
micromobility device-path	1	0	0	0	0	0	0	-1		
DATA PENALTY		-1	-1	-1	-1	-1	-1	-1	-3	
PATH DATA VALUE LESS PENALTY			3.2	3.2	3.2	3.2	3.2	3.2		-1
ELEMENT PENALTY		0	0	0	0	0	0	0	-1	
road-edge	1	-1	0	0	-1	-1	0	-1		
pedestrian-edge	1	-1	0	0	-1	-1	0	-1		
micromobility device-edge	0	0	-1	-1	0	0	-1	0		
DATA PENALTY		-2	-1	-1	-2	-2	-1	-2	-2	
EDGE DATA VALUE LESS PENALTY			-1	1.6	1.6	-1	-1	1.6		-1
ELEMENT PENALTY		-1	0	0	-1	-1	0	-1	-1	
pedestrian-zone	1	0	0	-1	0	0	-1	0		
motor vehicle-zone	1	0	0	-1	0	0	-1	0		
micromobility device-zone	1	0	0	-1	0	0	-1	0		
DATA PENALTY		0	0	-3	0	0	-3	0	0	
ZONE DATA VALUE LESS PENALTY			3.4	3.4	-1	3.4	3.4	-1		3.4
ELEMENT PENALTY		0	0	-1	0	0	-1	-1	0	
micromobility device-node	1	-1	0	-1	0	-1	-1	-1		
DATA PENALTY		-1	0	-1	0	-1	-1	-1	-1	
NODE DATA VALUE LESS PENALTY			-1	0.3	-1	0.3	-1	-1		-1
ELEMENT PENALTY		-1	0	-1	0	-1	-1	-1	-1	
micromobility device-landmark	0	0	0	0	0	0	0	0		
DATA PENALTY		0	0	0	0	0	0	0	0	
LANDMARK DATA VALUE LESS PENALTY			0	0	0	0	0	0	0	0
ELEMENT PENALTY		0	0	0	0	0	0	0	0	
micromobility device-district	0	0	0	0	0	0	0	0		
DATA PENALTY		0	0	0	0	0	0	0	0	
DISTRICT DATA VALUE LESS PENALTY			0	0	0	0	0	0	0	0
ELEMENT PENALTY		0	0	0	0	0	0	0	0	
<b>SCORING</b>										
STAKEHOLDER DATA VALUE		4.6	8.5	2.8	5.9	4.6	2.8	0.4		
VALUABLE DATA		###	81%	27%	56%	44%	27%	4%		
<b>RATING</b>										
REQUIRED ELEMENT DATA		2	4	2	3	2	2	1		
TOTAL ELEMENT PENALTY		-2	0	-2	-1	-2	-2	-3		
ELEMENT DATA FAILURE		50%	0%	50%	25%	50%	50%	75%		
Rated As:		Inappropriate	Acceptable	Inappropriate	Acceptable	Inappropriate	Inappropriate	Inappropriate		
RESULT		56%	81%	73%	56%	44%	73%	96%		
		Inappropriate	Acceptable	Inappropriate	Acceptable	Inappropriate	Inappropriate	Inappropriate		

# TEST 2 ARTEFACT 1 ANALYSIS & EVALUATION

**Table 4.22: Test 2-Artifact 1 Analysis**



			shape				label				weight				ANALYSIS drawing #1	
urban object	urban element	parameter	point	line/curve	plane	solid	text/symbol	line/curve	plane	solid	point area	thickn ess/colour	hatch/colour	hatch/colour	Sum	
			u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3		
1	road	path	visibility	0	1	0	0	0	1	0	0	0	1	0	0	
			count	0	2	0	0	0	2	0	0	0	2	0	0	
			amount	0	0.4	0	0	0	0.2	0	0	0	0.2	0	0	
															0.8	
0	motor vehicle	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	
			count	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	
															0.0	
1	pedestrian	path	visibility	0	1	0	0	0	1	0	0	0	1	0	0	
			count	0	6	0	0	0	10	0	0	0	3	0	0	
			amount	0	1.2	0	0	0	1	0	0	0	0.3	0	0	
															2.5	
1	micromobility device	path	visibility	0	0	1	0	0	0	1	0	0	0	1	0	
			count	0	0	1	0	0	0	4	0	0	0	1	0	
			amount	0	0	0.2	0	0	0	0.4	0	0	0	0.3	0	
															0.9	
1	3														4.2 PATH DATA VALUE	
0	road	edge	visibility	0	0	0	0	0	0	0	0	0	0	0	0	
			count	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	
															0.0	
0	pedestrian	edge	visibility	0	0	0	0	0	0	0	0	0	0	0	0	
			count	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	
															0.0	
0	micromobility device	edge	visibility	0	0	0	0	0	0	0	0	0	0	0	0	
			count	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	
															0.0	
0	0														0.0 EDGE DATA VALUE	
1	pedestrian	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	
			count	0	0	5	0	0	0	5	0	0	0	2	0	
			amount	0	0	1	0	0	0	0.5	0	0	0	0.2	0	
															1.7	
1	motor vehicle	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	
			count	0	0	3	0	0	0	2	0	0	0	2	0	
			amount	0	0	0.6	0	0	0	0.2	0	0	0	0.2	0	
															1.0	
1	micromobility device	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	
			count	0	0	1	0	0	0	4	0	0	0	1	0	
			amount	0	0	0.2	0	0	0	0.4	0	0	0	0.1	0	
															0.7	
1	3														3.4 ZONE DATA VALUE	
0	micromobility device	node	visibility	0	0	0	0	0	0	0	0	0	0	0	0	
			count	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	
															0.0	
0	0														0.0 NODE DATA VALUE	
0	micromobility device	landmark	visibility	0	0	0	0	0	0	0	0	0	0	0	0	
			count	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	
															0	
0	0														0 LANDMARK DATA VALUE	
0	micromobility device	district	visibility	0	0	0	0	0	0	0	0	0	0	0	0	
			count	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	
															0	
0	0														0 DISTRICT DATA VALUE	
2	VISIBLE ELEMENT DATA														7.6	AVAILABLE DATA VALUE
4	REQUIRED ANALYSED DATA															

**Table 4.23: Test 2-Artifact 1 Evaluation**

EVALUATION									
System calculates:									
urban object-urban element	urban element visibility	city planner	urban designer	engineer	pedestrian	micromobility device user	motor vehicle driver	building owner	
road-path	1	0	0	0	0	0	0	0	-1
motor vehicle-path	0	-1	-1	-1	-1	-1	-1	-1	0
pedestrian-path	1	0	0	0	0	0	0	0	-1
micromobility device-path	1	0	0	0	0	0	0	0	-1
DATA PENALTY		-1	-1	-1	-1	-1	-1	-1	-2
PATH DATA VALUE LESS PENALTY		3.2	3.2	3.2	3.2	3.2	3.2	3.2	-1
ELEMENT PENALTY		0	0	0	0	0	0	0	-1
road-edge	0	0	-1	-1	0	0	-1	0	
pedestrian-edge	0	0	-1	-1	0	0	-1	0	
micromobility device-edge	0	0	-1	-1	0	0	-1	0	
DATA PENALTY		0	-3	-3	0	0	-3	0	0
EDGE DATA VALUE LESS PENALTY		0	-1	-1	0	0	-1	-1	0
ELEMENT PENALTY		0	-1	-1	0	0	-1	0	0
pedestrian-zone	1	0	0	-1	0	0	-1	0	
motor vehicle-zone	1	0	0	-1	0	0	-1	0	
micromobility device-zone	1	0	0	-1	0	0	-1	0	
DATA PENALTY		0	0	-3	0	0	-3	0	0
ZONE DATA VALUE LESS PENALTY		3.4	3.4	-1	3.4	3.4	-1	-1	3.4
ELEMENT PENALTY		0	0	-1	0	0	-1	0	0
micromobility device-node	0	0	-1	0	-1	0	0	0	
DATA PENALTY		0	-1	0	-1	0	0	0	0
NODE DATA VALUE LESS PENALTY		0	-1	0	-1	0	0	0	0
ELEMENT PENALTY		0	-1	0	-1	0	0	0	0
micromobility device-landmark	0	0	0	0	0	0	0	0	
DATA PENALTY		0	0	0	0	0	0	0	0
LANDMARK DATA VALUE LESS PENALTY		0	0	0	0	0	0	0	0
ELEMENT PENALTY		0	0	0	0	0	0	0	0
micromobility device-district	0	0	0	0	0	0	0	0	
DATA PENALTY		0	0	0	0	0	0	0	0
DISTRICT DATA VALUE LESS PENALTY		0	0	0	0	0	0	0	0
ELEMENT PENALTY		0	0	0	0	0	0	0	0
<b>SCORING</b>									
<b>STAKEHOLDER DATA VALUE</b>		6.6	4.6	1.2	5.6	6.6	1.2	2.4	
<b>VALUABLE DATA</b>		87%	61%	16%	74%	87%	16%	32%	
<b>RATING</b>									
<b>REQUIRED ELEMENT DATA</b>		2	4	2	3	2	2	1	
<b>TOTAL ELEMENT PENALTY</b>		0	-2	-2	-1	0	-2	-1	
<b>ELEMENT DATA FAILURE</b>		0%	50%	50%	25%	0%	50%	25%	
<b>Rated As:</b>		Acceptable	Inappropriate	Inappropriate	Acceptable	Acceptable	Inappropriate	Acceptable	
<b>RESULT</b>		87%	39%	84%	74%	87%	84%	32%	
		Acceptable	Inappropriate	Inappropriate	Acceptable	Acceptable	Inappropriate	Acceptable	

## **4.3 EXPERIMENT 2**

Experiment 2 is an evaluation of three artefacts. The first is Artefact 2. The second is Test 1 Artefact 2 and the third is Test 2 Artefact 2. At the conclusion of the experiment, a comparison of the three results will be presented.

### **4.3.1 BACKGROUND ARTEFACT 2**

Experiment 2 examines a sample of a communication artefact used in an urban design project for micromobility infrastructure in Sydney. The project is a segment of Sydney Metro's East West Pedestrian and Cycling link (Link) to be located within the Lakemba town centre. Under Transport for NSW (TfNSW)'s Pedestrian Safety Program, this town centre has been zoned a High Pedestrian Activity Area (HPAA). The area is characterised by a main spine Haldon Street and fine grain commercial shop top housing buildings.

As part of the program administered by the Centre for Road Safety and in partnership with TfNSW, the speed limit will be reduced to a maximum of 40 km/h speed limit, and the redesign of Haldon Street will implement a traffic calming environment within the town centre to enforce the new speed limit.

The town centre of Lakemba also hosts an award-winning event held once a year during a one-month period. The event is recognised as being of State-significance as it welcomes over 1.4 million people in the town centre. Road closures and detour routes are in place during the one-month event. During which Haldon Street transforms into a fully pedestrianised event space with outdoor high energy atmosphere and food stalls.

The key strategic pedestrian priority is to enhance pedestrian amenity with wider footpaths and improve bio-diverse human-scale interventions along Haldon Street and around the town centre. The slower speed limit will ensure pedestrians can move safely along the main

strip of Haldon Street. However, a cycleway will also need to be accommodated to share to road with pedestrians and motor vehicles.

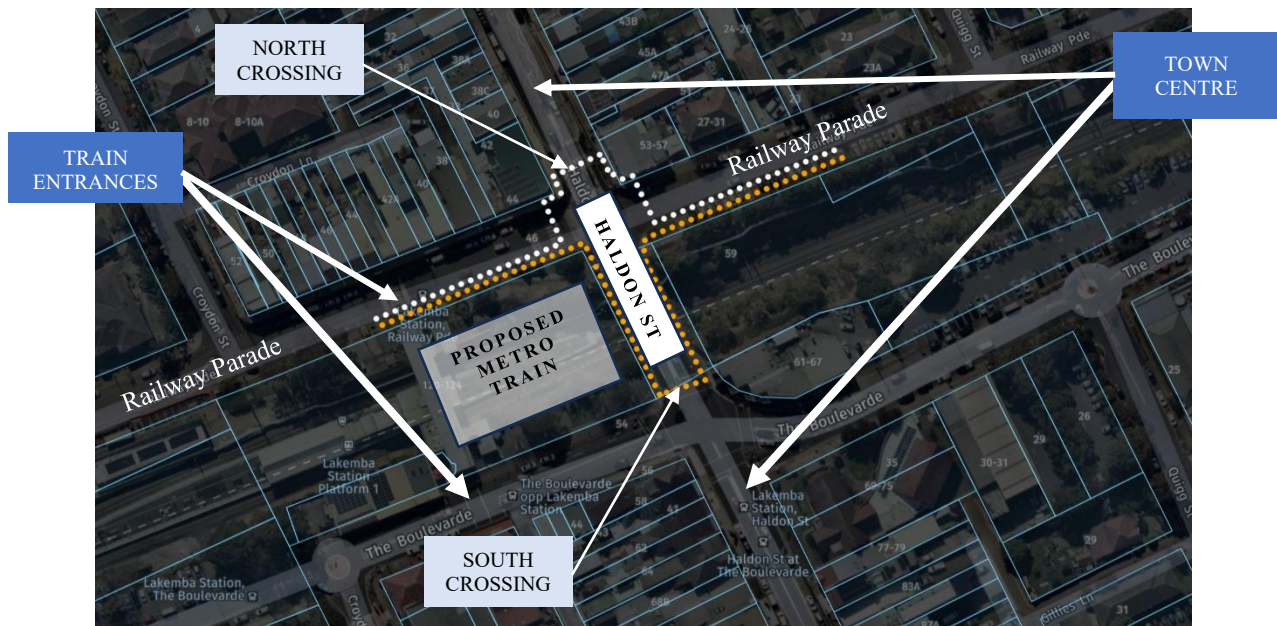


Figure 4.20: Project 2, cycleway proposed crossing routes.

As such the above image taken from *Nearmap* shows the relevant road, the boundaries and town centre context to illustrate the project’s significance to road users, pedestrians and the local and business communities.



NORTH  
CROSSING

Figure 4.21: Google street view. Haldon Street at the intersection of Railway Pde.

### Technical Constraints

Haldon Street, at the segment over the train line, has a median strip to separate the bi-directional road traffic. This poses a barrier for direct crossing by cyclists travelling along Railway Parade. To remove a segment of the median strip to create a direct crossing for cyclists does not meet traffic regulations due to the close distances to the existing north and south crossing. Cyclists must determine a way across, which is either crossing at a dedicated pedestrian crossing a few meters north or at the first signalised crossing a few meters south along The Boulevard. Haldon Street is also a single-lane bi-directional traffic condition with dedicated parking on both sides through the town centre. At the segment over the Metro train, Haldon Street bridge over the Metro train becomes a two-lane bi-directional traffic with narrow footpaths on both sides. As traffic crosses over to the other side of the train line, traffic reverts back to a single-lane bi-directional traffic with dedicated parking on both sides.

The north crossing means cyclists will have to go through the town centre along the footpath interfacing the retail frontages to reach the dedicated pedestrian north crossing. This means a cyclist will use the active heavily pedestrianised space along the shopfronts to reach the crossing point. There are some planter boxes and street furniture as well as outdoor dining in this space. There is no available space on the Haldon Street carriageway to dedicate a lane for cyclists to allow them to reach the break in the median strip and safely cross along the pedestrian crossing. Without design intervention, the north crossing proposal may result in pedestrian and cycling conflict in the shopfront space.

The south crossing presents a different constraint. The footpaths over the train line along either side of the carriageway are narrow and the two-lane bi-directional traffic has no available space to accommodate a dedicated cycleway for cyclists to travel on Haldon Street to reach the break in the median lane and cross over Haldon Street safely at the lights. The south crossing means cyclists will either use the narrow footpath which will result in high risk of pedestrian

and cycling conflict, or use the carriageway dedicated for vehicle traffic which will also pose a high risk for cyclists.

### Conditions and Current Use

Haldon Street is the main spine of Lakemba's commercial precinct. It is highly activated during the day and at night with eateries and retail. There is heavy movement of pedestrians and vehicles along Haldon Street but little or none can be seen of cyclist movement. There is congestion of vehicle traffic during peak hours due to the slowed down HPAA which recognises Haldon Street as a pedestrian priority area. The shopfronts near the junction of the train line are characterised by outdoor dining, street furniture and planter boxes, with heavy pedestrian movement. There is little to no cycling that can be observed.

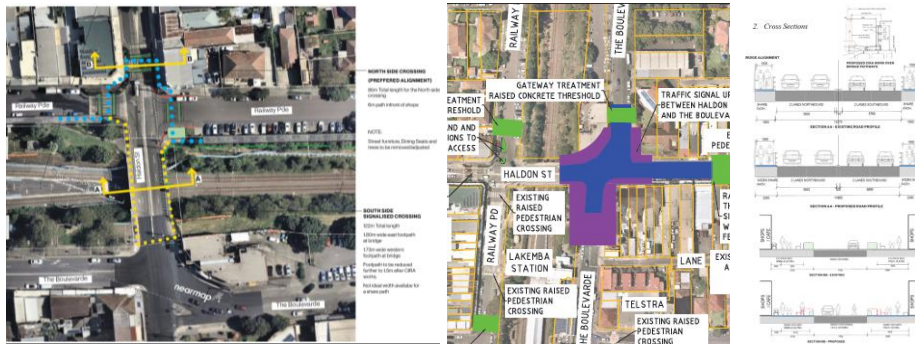
### Project Proposal

As part of the delivery of an east west pedestrian and cycling link, the project proposed a number of design solutions to accommodate the state government's cycling priority infrastructure, to keep all road users safe which include motor vehicles, micromobility devices, and pedestrians at all hours, as well to support the priorities of the town centre.

There have been many design iterations proposed for both the north and the south cycling alignment. It included various design solutions of the dog-leg through the town centre as well including dismounted cyclists. Cyclists will have to travel along the route through the town centre that stretches over a total of 170 meters to cross Haldon Street for slower movement, however this would require more space as the cyclist walks beside the bicycle.

The urban design activities involved during the design process is extensive. The following list of actions that were undertaken, which is not exhaustive: multiple site investigations, traffic and movement studies, identification and analysis of physical limitations, opportunities and other regulatory constraints, development of preliminary concept technical

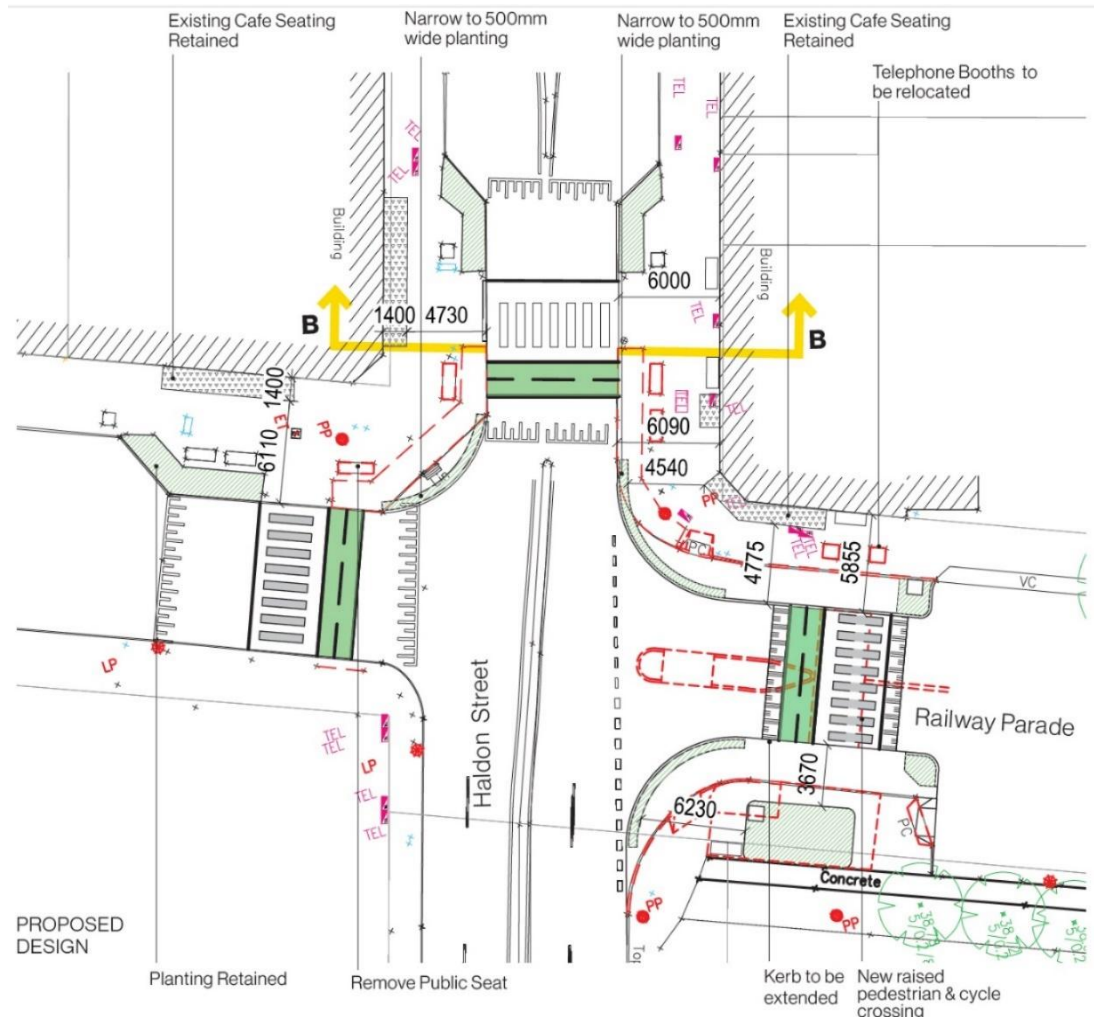
designs, stakeholder technical working group meetings and reviews, iterative design development as well as ongoing technical working group workshops, community consultations, project control group reviews and meetings and an ongoing list of activities involving iterative design and coordination.



**Figure 4.22:** Communication artefact samples.

Weekly meetings of the technical working group made up of key stakeholders from the public sector took place to discuss investigations and possible solutions. In these meetings communication artefacts were critical to discuss and communicate movement and technical information relating to the proposed design. Design iterations communicated had to be able to convey physical constraints, site and technical details, movement issues and communicate concept design iterations. Communication artefacts were extensive, varied and numerous and were a critical part of the urban design process. The general stakeholders that need to be consulted about the project are from public and private sectors with varying priorities and objectives concerning this urban design project. They are a mix of domain and non-domain experts and professionals. Due to the nature of the project from a technical, social, environmental, economic and governmental perspective, this was considered a complex urban design project. Artefact 2 for Experiment 2 is a sample of the communication artefact used during the design development process.

## ARTEFACT 2



**Figure 4.23:** Artefact 2.

This is a sample of a communication artefact used in this urban design project. This is Artefact 2 to be analysed and evaluated for Experiment 2. This shows a different level of detail compared to Artefact 1 which has information from the map underlay. The level of detail appears to be semi-technical and part of working drawings. Communication of movement was integral in the process due to the nature of the proposal. The movement of pedestrians, cyclists and motor vehicles were significant considerations in the process and is vital to the success of the project.

### 4.3.2 ARTEFACT 2 – LAYERS ANALYSIS

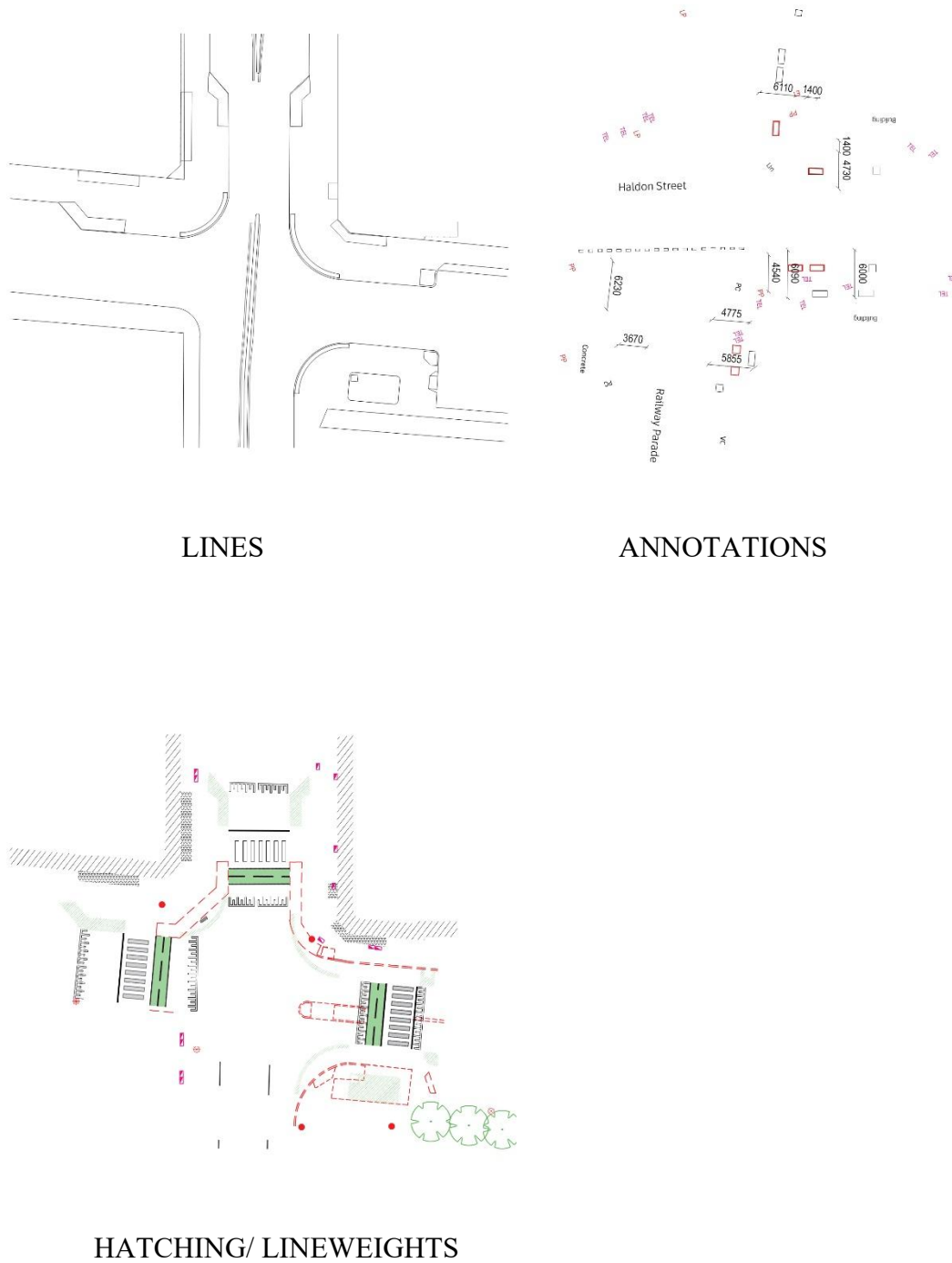


Figure 4.24: Artefact 2 Shape Analysis.

Artefact 2 is a 2D communication artefact and is rationalised into layers of information. As such, Artefact 2 is considered to have the following data layers including the shape geometry of line, and the graphical information attributes of weight such as line weights and hatching or shading, and the graphical information attributes of label such as annotations.

#### LINES ANALYSIS | GRAPHIC ALGEBRA:

SHAPE = LINE

ALGEBRA =  $U_{12} W_1$ , where  $U_{12}$  is line on 2D and  $W_1$  is line type

Road-edge: 5

Pedestrian-edge: 4

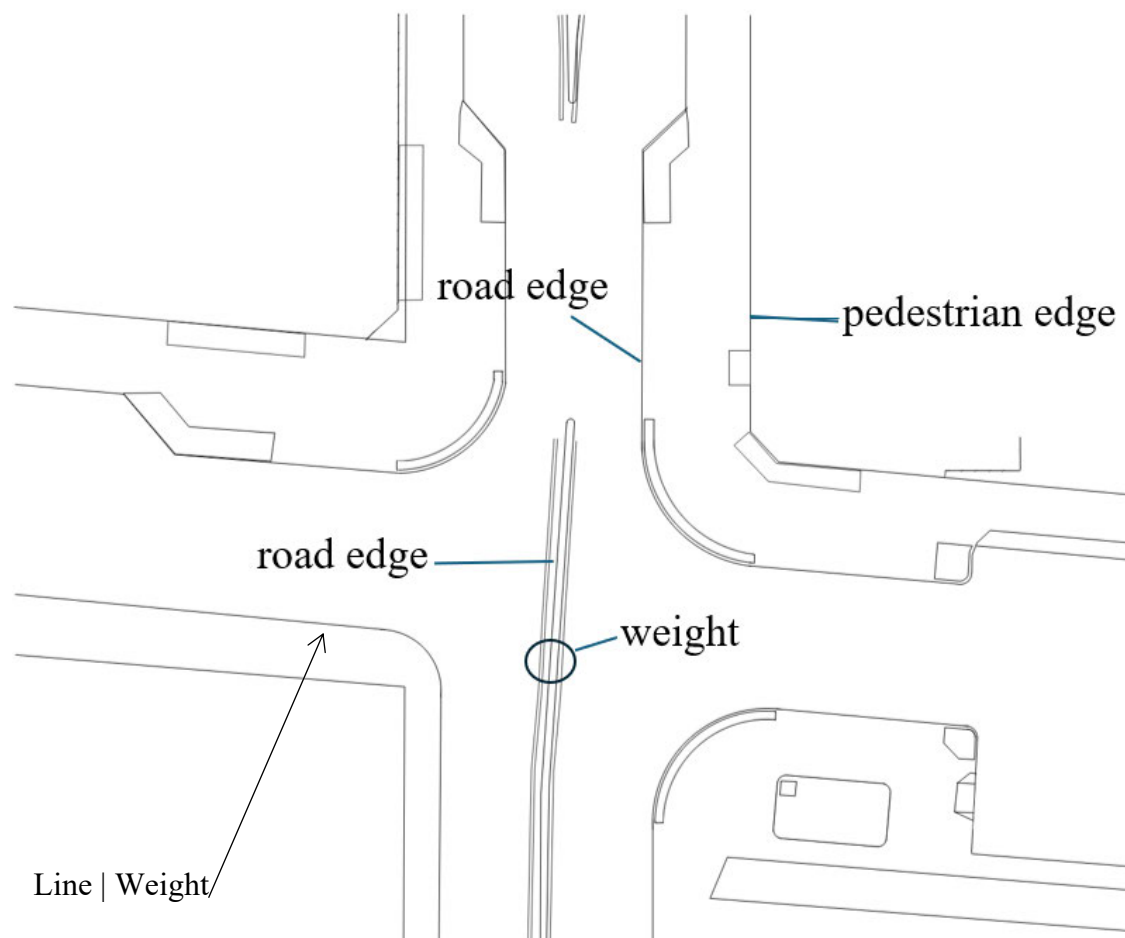


Figure 4.25: Artefact 2 Line Shape Analysis.

As shown in the above lines, it can be observed that lines/curves have various functions to communicate towards understanding different elements in the artefact. The road edge can be identified along the edges of the carriageway, hence there are four distinct line curves. There are also line curves to represent edges along the footpath for pedestrians to travel along on. The lines in the middle of the road is identified as one line with weight, as weight is used to put an emphasis and highlight the line and its significance.

#### HATCHING/LINEWEIGHTS ANALYSIS | GRAPHIC WEIGHTS

SHAPE = PLANE

ALGEBRA =  $U_{2,2} W_1$ , where  $U_{2,2}$  is plane on 2D and  $W_1$  is hatch

Road-edge: line 2, with weight 2 (colour: red and linetype: dash)

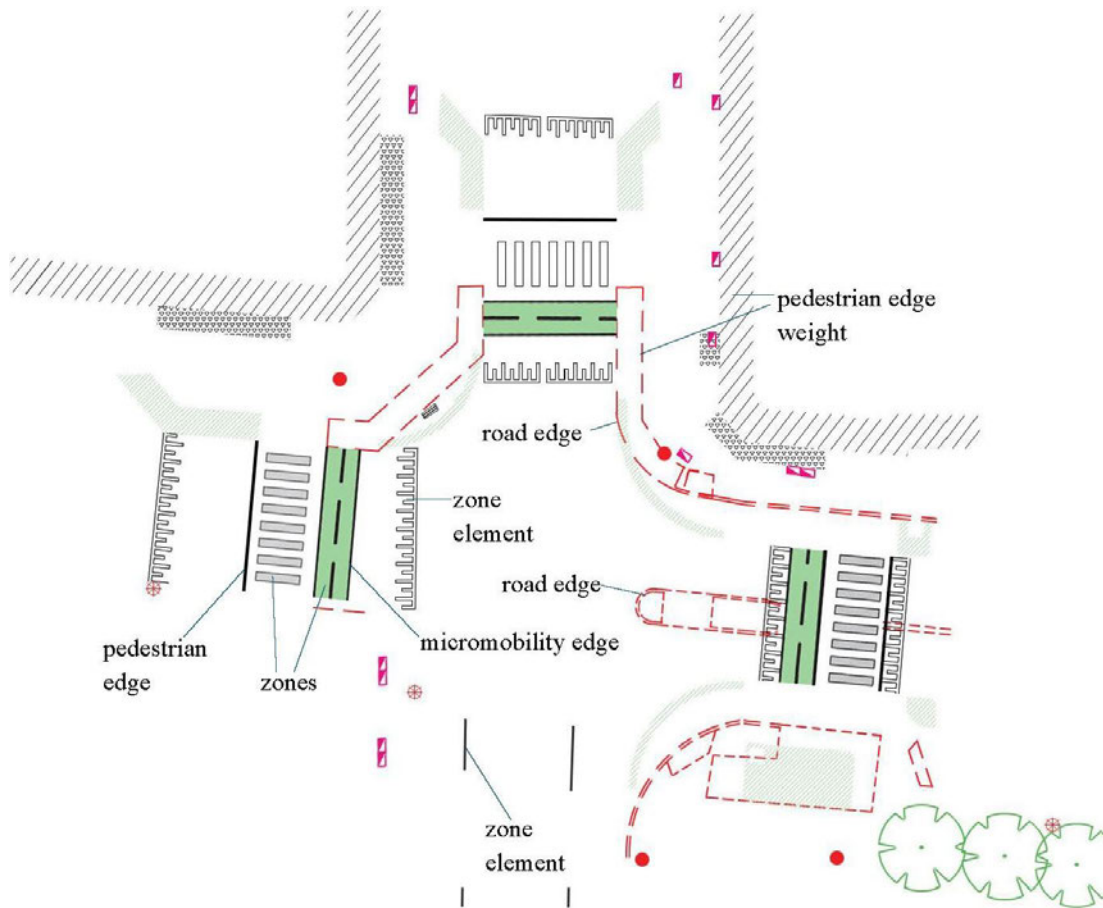
Pedestrian-edge: line 3 with weight 1; plane 2 with weight 1 (hatching)

Micromobility-edge: line 6 with weight 1

Pedestrian-zone: plane 3 with weight 1

Motor vehicle-zone: line 8 with weight 4

Micromobility-zone: plane 3 with weight 1



**Figure 4.26:** Artefact 2 Line and Plane Weights Analysis.

The above shows weight graphical attributions used on points, lines/curves and planes shape geometries. The process identifies what they are and how they add value to information. As example, the building boundary is identified here as pedestrian edge for the purpose of communicating the design that involves pedestrian movement.

GRAPHIC WEIGHTS ALGEBRA

Table 4.24: Artefact 2 Line and Plane Weights

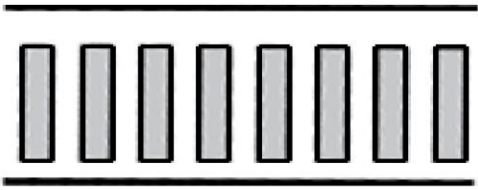
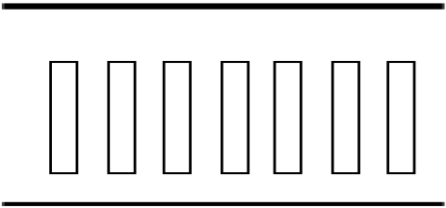





	SHAPE: LINE/PLANE   WEIGHT	ALGEBRA
1		$U_{11} W_1$ (edge) $U_{22} W_1$ (zone)
2		$U_{11} W_1$ (edge) $U_{22} W_1$ (zone)
3		$U_{11} W_1$ (edge) $U_{22} W_1$ (zone)
4		$U_{22} V_1$ (zone)
5		$U_{11} W_2$ (edge)
6		$U_{11} W_1$ (edge)
7		$U_{22} V_1$ (zone)

Table 4.25: Artefact 2 point and plane weights

	SHAPE: POINT   WEIGHT	ALGEBRA
1		$U_{00} W_2$
2		$U_{00} W_2$
3		$U_{00} W_2$
4		$U_{00} W_2$
	SHAPE: PLANE   WEIGHT	ALGEBRA
5		$U_{22} W_2$
6		$U_{22} W_2$
7		$U_{22} W_2$

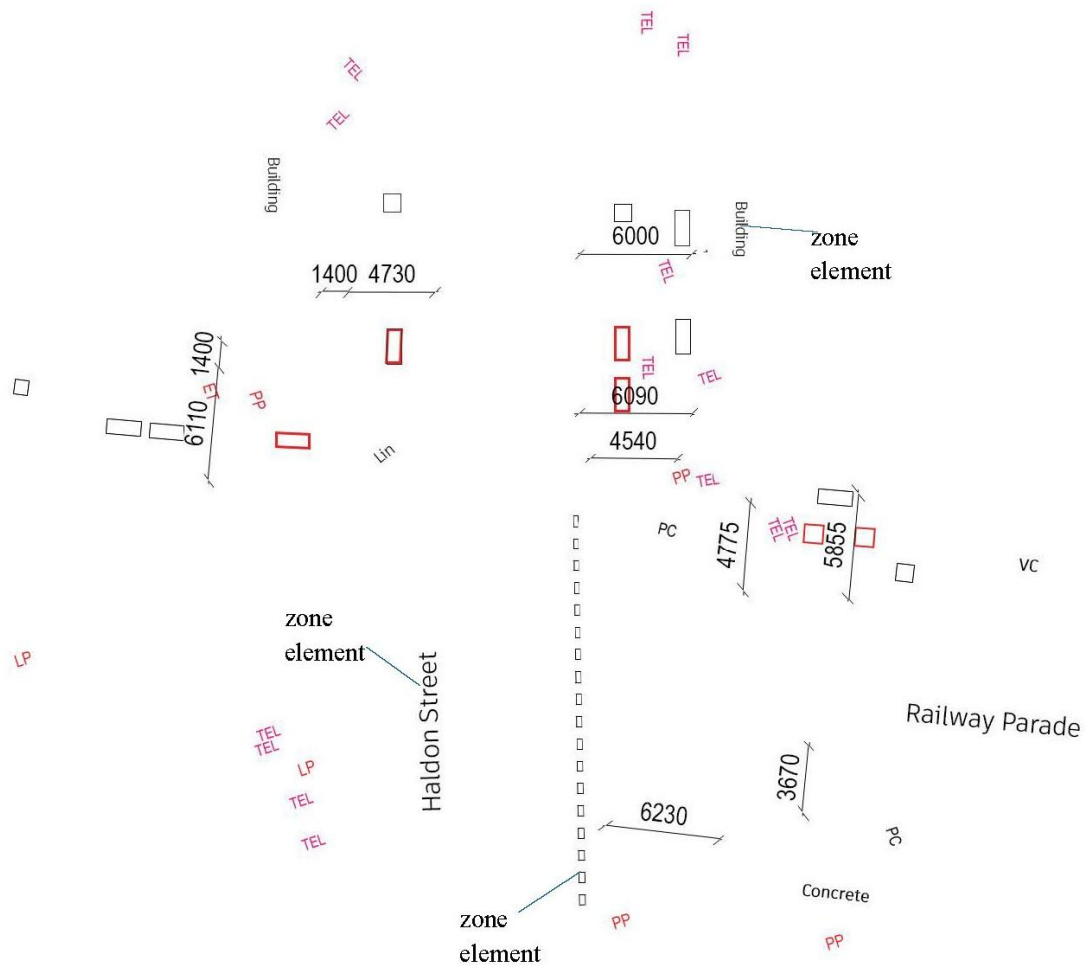
## ANNOTATIONS ANALYSIS | GRAPHIC LABELS

SHAPE = PLANE

ALGEBRA =  $U_{22} V_1$ , where  $U_{22}$  is plane on 2D and  $V_1$  is label

Pedestrian-zone: label 3

Motor vehicle-zone: label 3


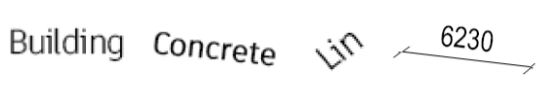

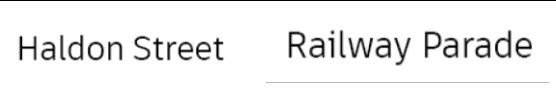
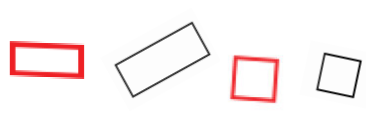


**Figure 4.27:** Artefact 2 labels analysis.

The above shows label graphical attributions used on points, lines/curves and planes shape geometries to add another layer of information to shapes. For the purpose of the research, the labels will be grouped in sets as they're similar. Generally, except for arrows which function

distinctly to point at different directions and must be counted separately, labels that identify a spot, items or material type can be grouped as one count.

**Table 4.26: Artefact 2 label sets**

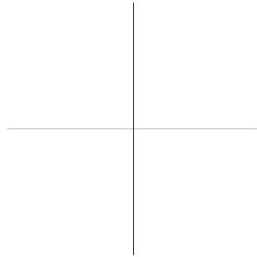
	LABEL SET 1	ALGEBRA
1		$U_{00} V_1$
2		$U_{22} V_1$
3		$U_{22} V_1$
	LABEL SET 2	
1		$U_{22} V_1$
	LABEL SET 3	
1		$U_{22} V_1$

As can be observed, this layer of information presents various label graphical information attributes for the plane  $U_2$  geometry. As example, it identifies that items in Label Set 1 for the underlying plane which is enhanced by this graphical information attribute, labels of symbols and location texts as shown in Label Set 2.

These collected statistics analysis data will be used as reference for the system analysis for Artefact 1 and the system evaluation.

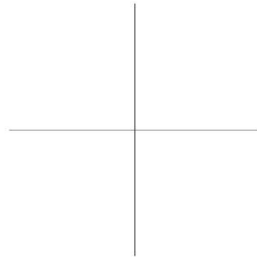
### 4.3.3 ARTEFACT 2- STATISTICAL ANALYSIS

#### GEOMETRIC ELEMENT LAYERS ALGEBRA



**Road straight paths**

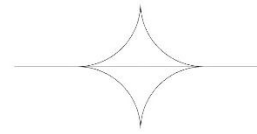
U1 2 (line on 2D space)



**Road straight paths and nodes**

U1 2 (line on 2D space)

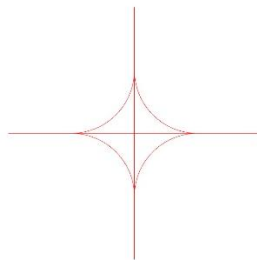
U0 2 (point on 2D space)



**Road curved and**

**straight paths**

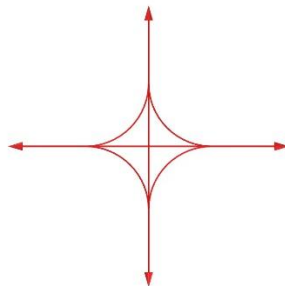
U1 2 (line on 2D space)



**Road weighted paths**

U1 2 (line on 2D space)

W1 2 (shade/colour on  
1D shape)



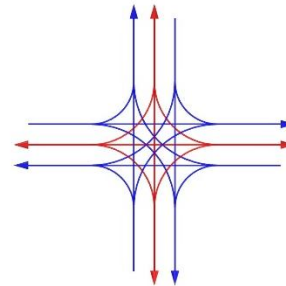
**Road weighted and**

**labelled paths**

U1 2 (line/curve on 2D  
space)

V0 1 (point/symbol on  
1D shape)

W1 2 (shade/colour on  
1D shape)



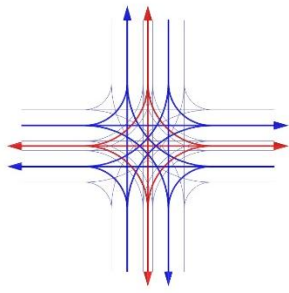
**Car weighted and**

**labelled paths**

U1 2 (line, arc)

V0 1 (arrow)

W1 2 (red, blue)



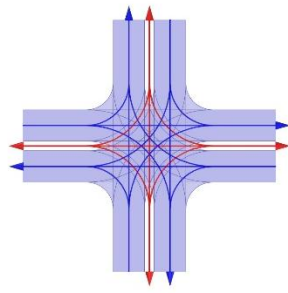
**Cars movement space**

**boundaries**

U1 2 (line, arc)

V0 1 (arrow)

W1 2 (red, blue)



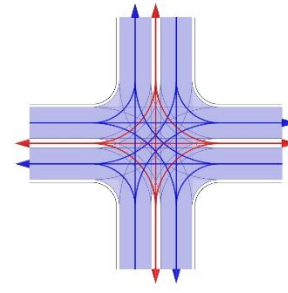
**Cars movement**

**weighted space**

U1 2 (line, arc)

V0 1 (arrow)

W1 2 (red, blue, purple)

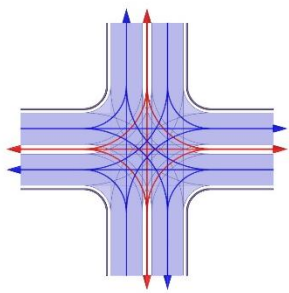


**Road boundaries**

U1 2 (line, arc)

V0 1 (arrow)

W1 2 (red, blue, purple)



**Road weighted space**

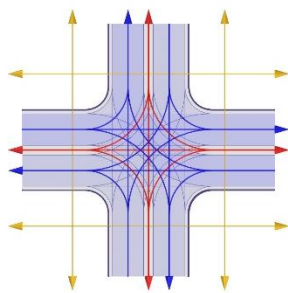
U1 2 (line, arc on 2D space)

U2 2 (surface n 2D space)

V0 1 (point/symbol on 1D shape)

W1 2 (colour/thickness on 1D shape)

W2 2 (colour/hatch on 2D shape)



**Pedestrian movement**

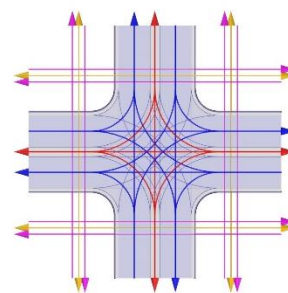
U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red, blue grey, yellow)

W2 2 (grey)



**Pedestrian bi-direction movement**

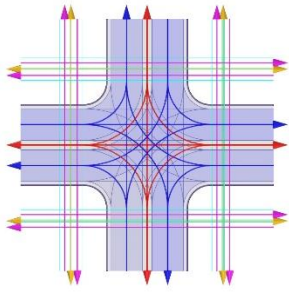
U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red, blue grey, yellow, magenta)

W2 2 (grey)



**Pedestrian bi-direction**

**boundary**

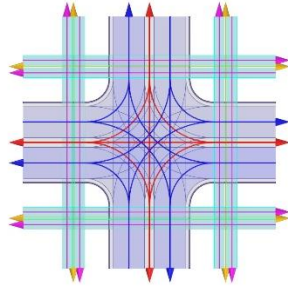
U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red, blue grey,  
yellow, magenta, cyan)

W2 2 (grey)



**Pedestrian bi-direction**

**movement space**

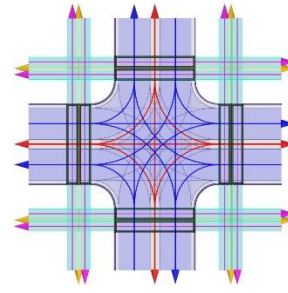
U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red, blue grey,  
yellow, magenta, cyan)

W2 2 (grey, cyan)



**Pedestrian road**

**crossing boundary**

U1 2 (line, arc)

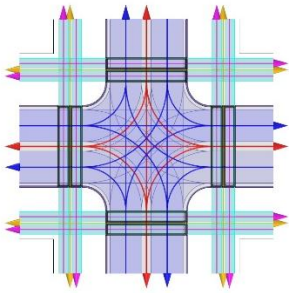
U2 2 (surface)

V0 1 (arrow)

W1 2 (red, blue grey,  
yellow, magenta, cyan,

dark grey)

W2 2 (grey, cyan)



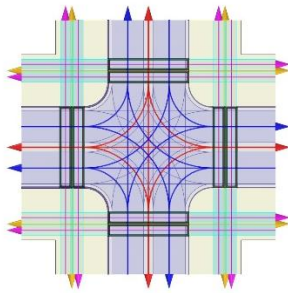
**Pedestrian footpath**

**boundary**

U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)



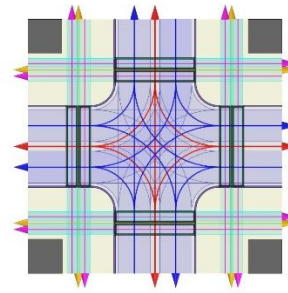
**Pedestrian footpath**

**surface**

U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)



**Building footprint**

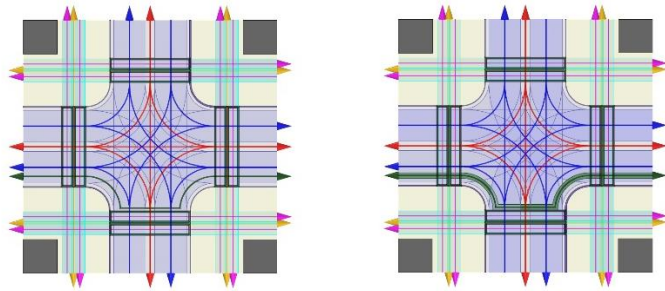
**surface**

U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red, blue grey, yellow, magenta, cyan, dark grey)	W1 2 (red, blue grey, yellow, magenta, cyan, dark grey)	W1 2 (red, blue grey, yellow, magenta, cyan, dark grey)
W2 2 (grey, cyan)	W2 2 (grey, cyan, yellow)	W2 2 (grey, cyan, yellow, black)



**On-road cycleway**

**direction**

U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red, blue grey,  
yellow, magenta, cyan,  
dark grey, green)

W2 2 (grey, cyan, yellow,  
black)

**On-road cycleway road**

**space**

U1 2 (line, arc)

U2 2 (surface)

V0 1 (arrow)

W1 2 (red, blue grey,  
yellow, magenta, cyan,  
dark grey, green)

W2 2 (grey, cyan, yellow,  
black, green)

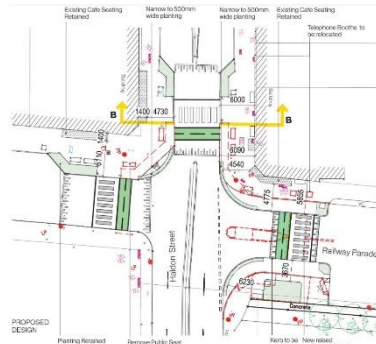
**Figure 4.28:** Artefact 2 geometric transformation analysis.

As shown in this table, the same shape geometries identified in the shape analysis can be manipulated and adjusted to produce variations. The geometric algebra and calculations are

carried out based on assumptions and conditions set from the start of the process. As can be observed the graphics look very similar, however slight changes can produce or deduct layers of information.

Similarly to Artefact 1 analysis, in examining the graphic representations in the table, a path, which is described as a channel or route for travelling along, for communication purposes will need to be conveyed distinctly from edge. The process will assume that if the line is in the middle of the road instead of being located at the boundary of the carriageway, then the line is considered a path. In the same way an edge can be identified as it generally sits along the boundary to delineate one area from another. As well, if a line has direction labels such as arrows, regardless of whether it is located in the middle of the road or at the edge, it signifies that it is a path for travelling along, a typical assumption across all four experiments. Based on these assumptions and conditions, Artefact 2's statistical analysis are entered in the system as shown in Table 4.27.

### 4.3.4 ARTEFACT 2 – ARTEFACT ANALYSIS & EVALUATION



**Figure 4.29:** Artefact 2

**Table 4.27:** Artefact 2 geometry count

	Shape	Label	Weight
<i>Path</i>	0	0	0
<i>Edge-road</i>	U1=9	0	W1=3
<i>Edge-pedestrian</i>	U1=7, U2=2	0	W1=1, W2=1
<i>Edge-micro device</i>	U1=6	0	W1=1
<i>Zone-pedestrian</i>	U2=3	V2=3	W2=1
<i>Zone-motor vehicle</i>	U1=10	V2=3	W1=4
<i>Zone-micro device</i>	U2=3	0	W2=1
<i>Node-micro device</i>	0	0	0

## ARTEFACT 2 SYSTEM ANALYSIS:

Based on the graphical layers analysis, the system calculated the graphical statistics and calculated the values based on Calibration table 3.

The Available Data Value is 9.8 which is the total value of the artefact based on the visible urban elements combined. The system also calculated the number of urban elements in the artefact. Artefact 2 has a total of 2 elements, edge and zone (Visible Element Data). The analysis for Artefact 2 in Experiment 2 shown in the tables in Sub-Section 4.3.8 and the summary breakdown of the data values are shown below:

**Table 4.28: Artefact 2 Analysis Summary**

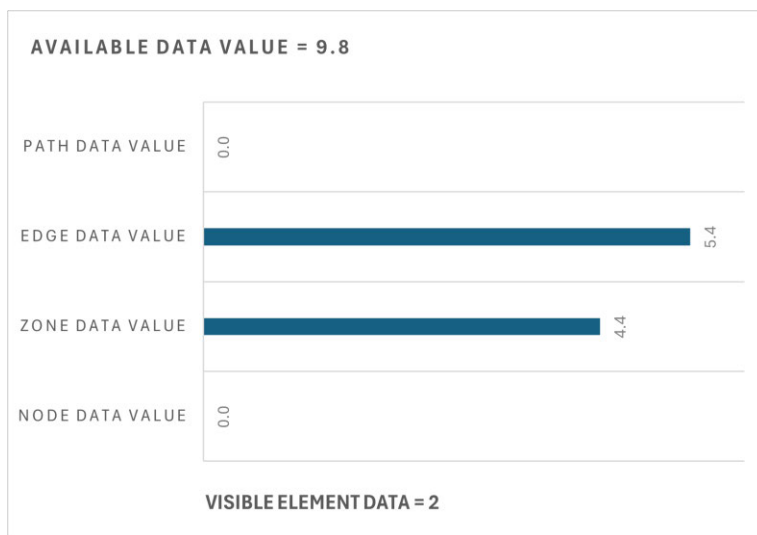
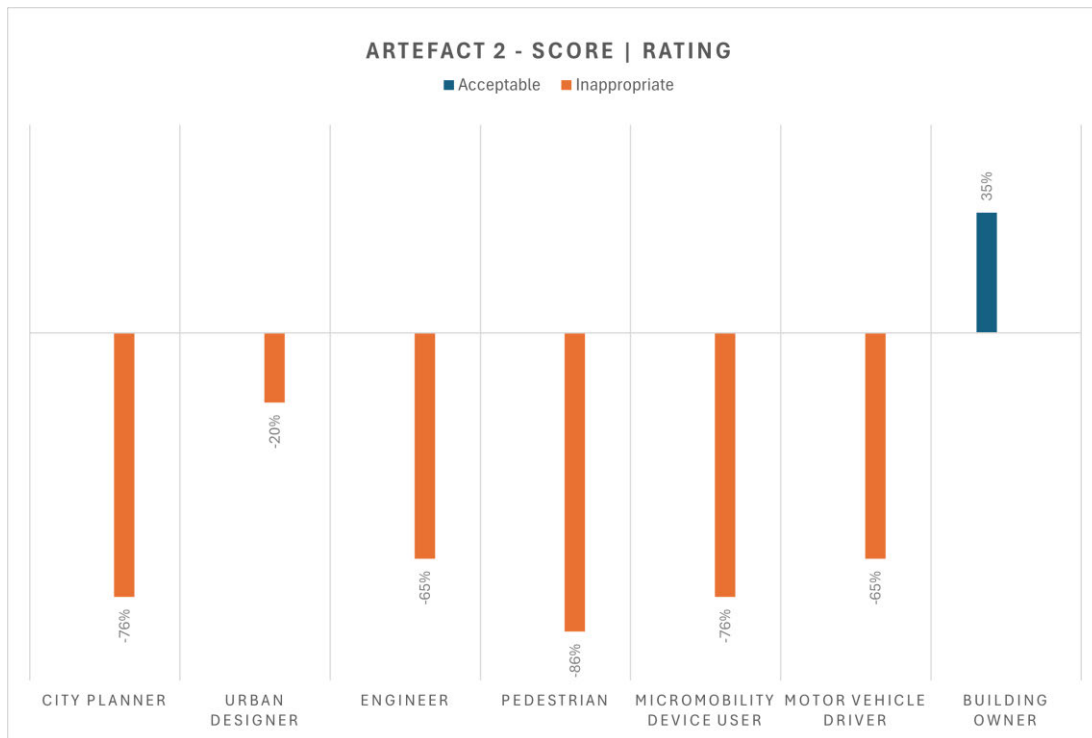


Table ##. Artefact 2 Analysis Summary

Based on the assumptions path urban element is not featured in Artefact 2. Hence, the path data value is zero. Node also is zero and the urban elements of landmark and district have been turned off to avoid bias. These data values are automated inputs to the evaluation phase 2 of the system for Artefact 2.

## ARTEFACT 2 SYSTEM EVALUATION

**Table 4.29: Artefact 2 Evaluation Summary**

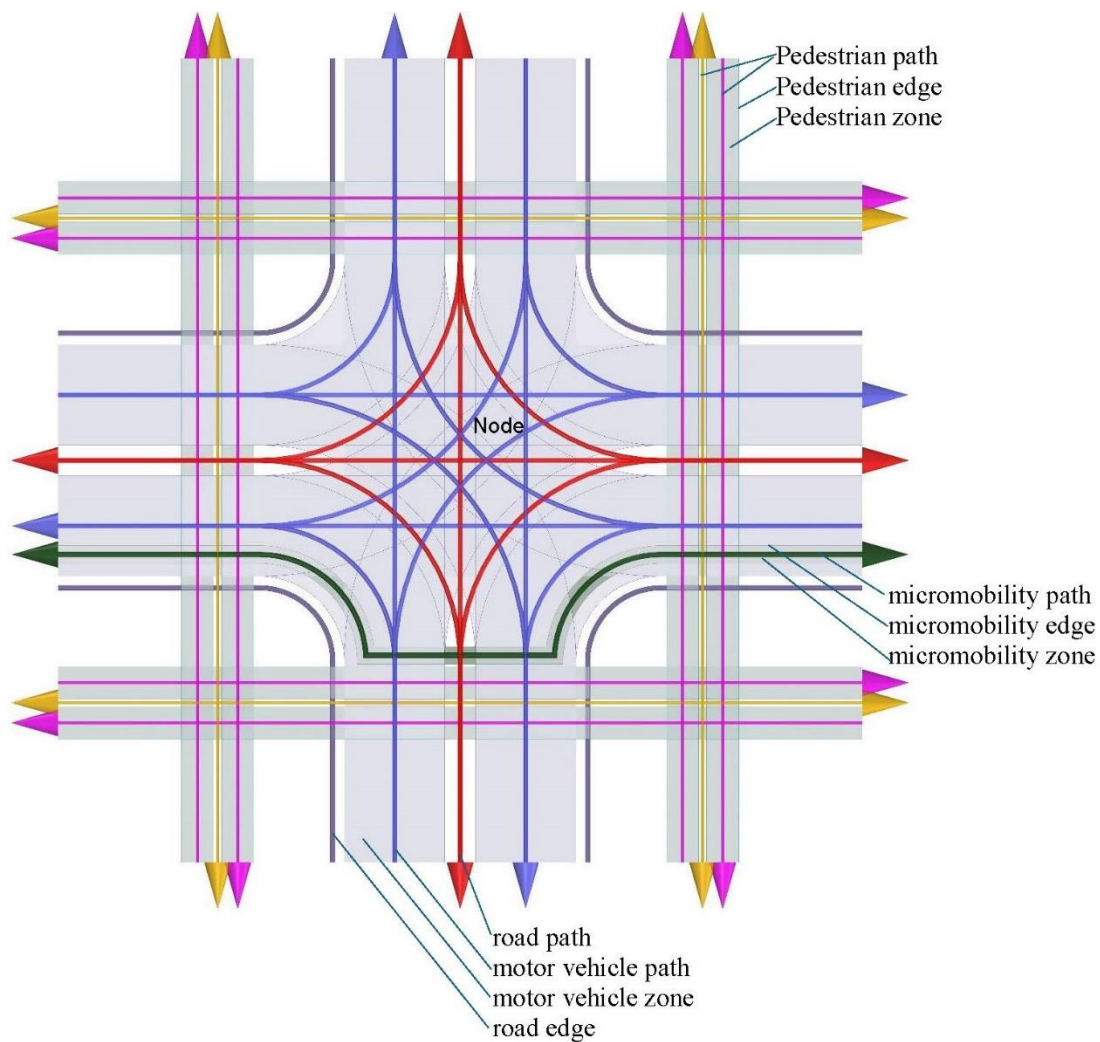


The chart above shows the summary of artefact evaluation against stakeholders' requirements set out in Calibration Table 1. Based on the given artefact and the parameters set out in Calibration Table 2, the artefact was measured with a Score and a Rating. The blue bar means the artefact is acceptable to Building Owner stakeholder, whilst the orange bars mean the artefact is inappropriate to City Planner, Urban Designer, Engineer, Pedestrian, Micromobility Device User and Motor Vehicle Driver stakeholders.

As such, based on the Available Data Value = 9.8, and the Visible Element Data = 2 of Artefact 2, the Result shows the artefact's score and rating for each stakeholder in the table shown in Sub-Section 4.3.8.

### 4.3.5 TEST 1 – Artefact 2

Test 1 Artefact 2 presents a variation to the graphical data in Artefact 2 and is customised to improve its performance for the *urban designer* stakeholder. The test artefact is not a precise replica but a rendition of Artefact 2 to demonstrate the graphic transformation of geometry based on the original artefact geometry.



**Figure 4.30:** Test 1 Artefact 2.

According to Calibration table 1, urban designer stakeholder requires information on path, edge, zone and node. With the view of improving the performance of Artefact 2 for the urban designer stakeholder for the purpose of testing the system, Path and node data values are

missing in Artefact 2. Observe the increase in shapes for edge and zone, as well the addition of path with labels and weights, and addition of node.

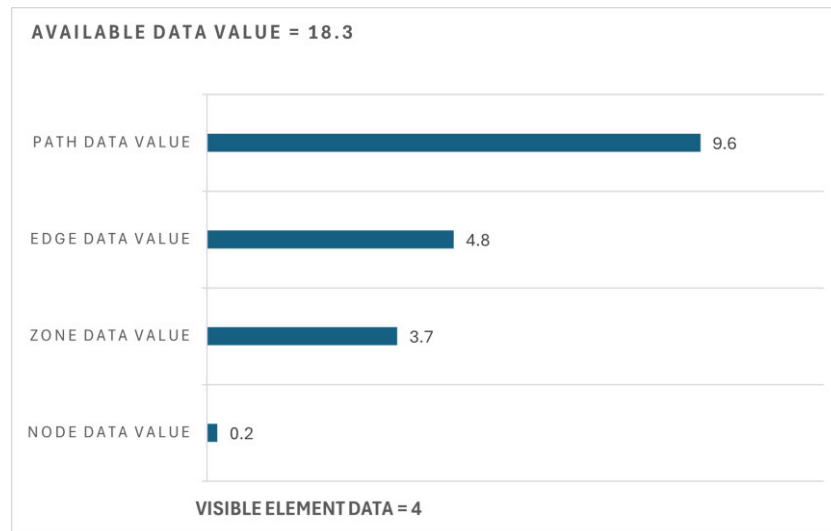
**Table 4.30: Test 1 Artefact 2 geometry count**

	Shape	Label	Weight
<i>Path-road</i>	U1=6	V1=4	W1=2
<i>Path-motor vehicle</i>	U1=12	V1=4	W1=2
<i>Path-pedestrian</i>	U1=12	V1=16	W1=2
<i>Path-micro device</i>	U1=1	V1=2	W1=2
<i>Edge-road</i>	U1=4	0	W1=2
<i>Edge-pedestrian</i>	U1=16	0	W1=1
<i>Edge-micro device</i>	U1=2	0	W1=1
<i>Zone-pedestrian</i>	U2=8	0	W2=1
<i>Zone-motor vehicle</i>	U2=8	0	W2=1
<i>Zone-micro device</i>	U2=1	0	W2=1
<i>Node-micro device</i>	U0=1	0	W0=2

#### TEST 1 ARTEFACT 2 SYSTEM ANALYSIS:

The above table shows the geometry count for Test 1 Artefact 2. The result summary of the analysis for Test 1 Artefact 2 is shown below which shows the addition of path and node and a slight increase in edge and zone data values compared to Artefact 2 analysis. The analysis table is Sub-Section 4.3.8.

The System Analysis for the Test 1-Artefact 2 in Experiment 2 shows:



**Table 4.31: Test 1 Artefact 2 Analysis Summary**

TEST 1 ARTEFACT 2 SYSTEM EVALUATION:

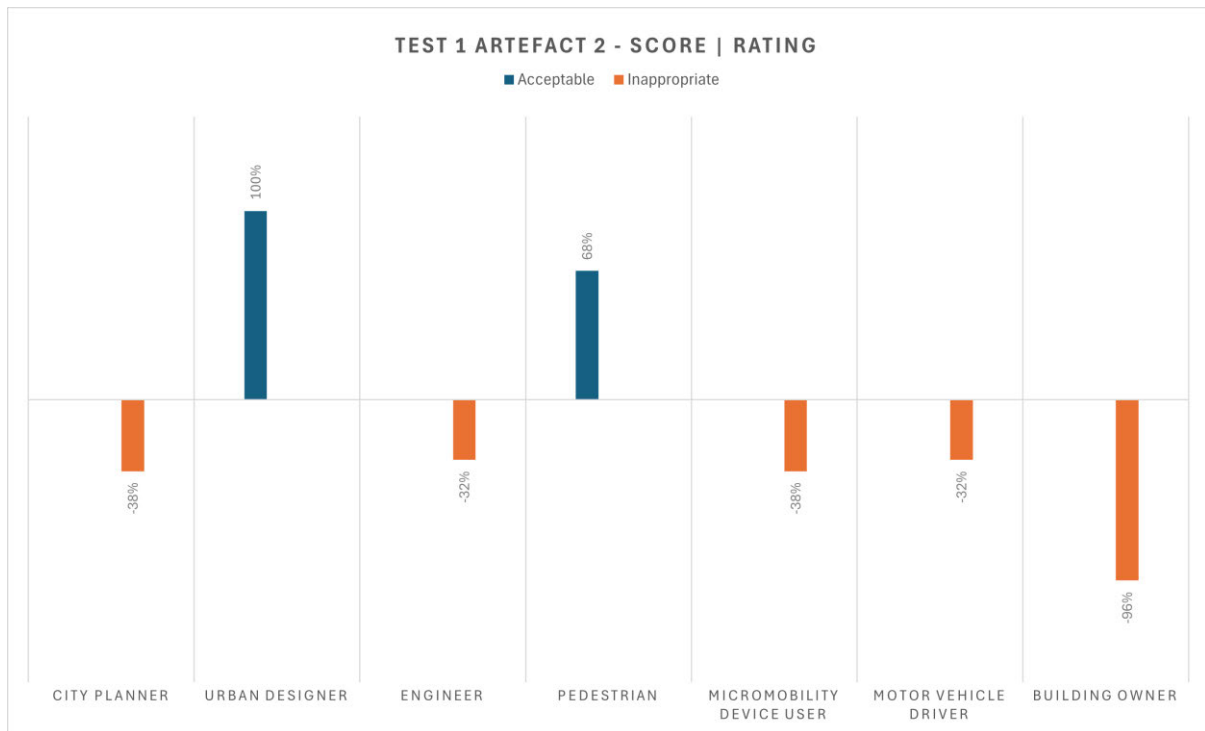
The System Evaluation for the Test 1 Artefact 2 in Experiment 2:

The system evaluated the artefact's statistical data analysis against the requirements set out for individual stakeholders. The system produced an autogenerated result as shown in the evaluation table in Sub-Section 4.3.8 for Test 1 Artefact 2 Evaluation.

The table shows the result of the evaluation for Test 1 Artefact 2 which shows a score of 100% Acceptability, a significant improvement on the performance of the artefact for urban designer.

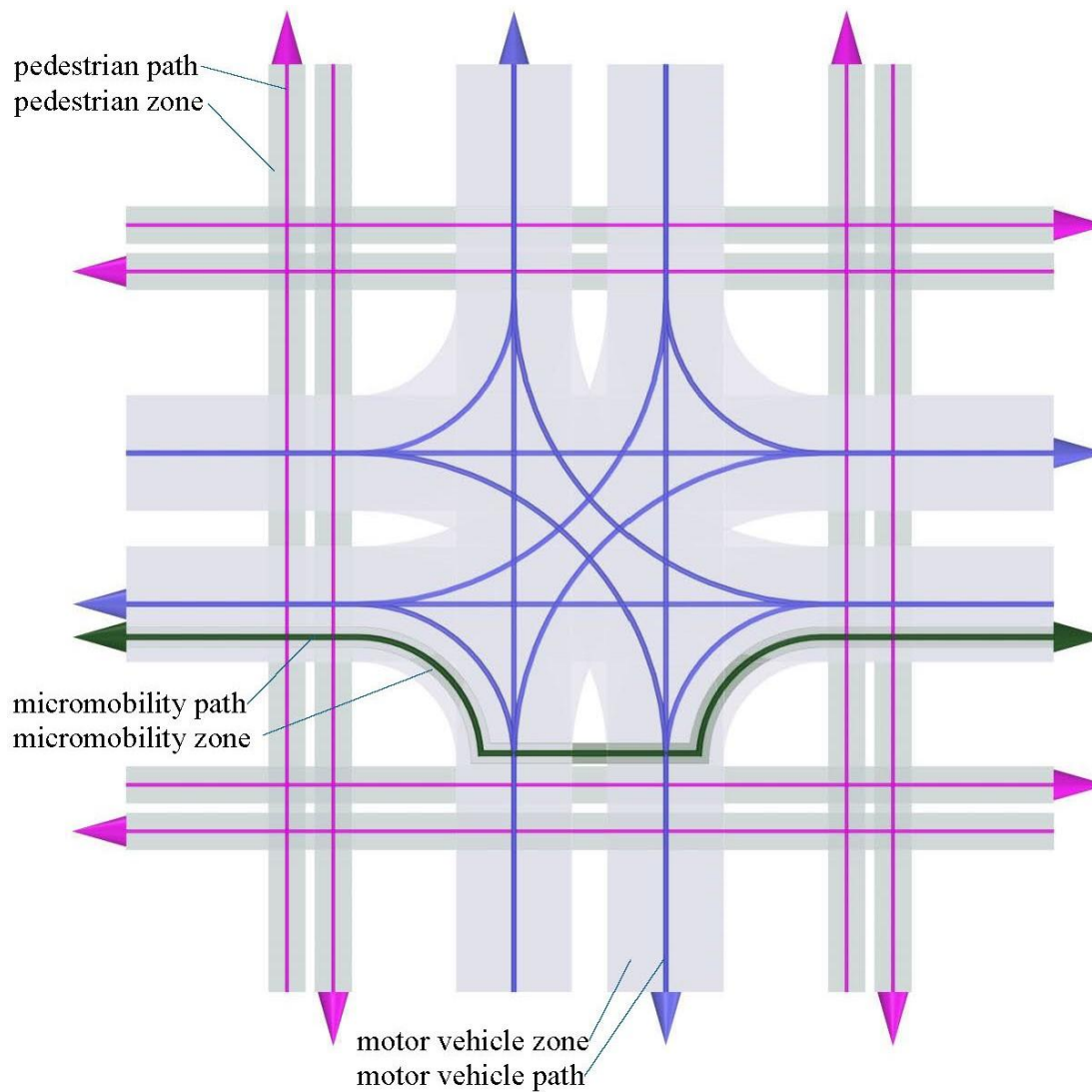
Based on the Available Data Value = 18.3, and the Visible Element Data = 4 of Test 1 Artefact 2, the summary of the Result is shown in the chart below for the artefact's score and rating for each stakeholder:

**Table 4.32: Test 1 Artefact 2 Evaluation Summary**



#### 4.3.6 TEST 2 – Artefact 2

Test 2 Artefact 2 also presents another variation to the graphical data in Artefact 2 and is customised to improve its performance for the micromobility device user stakeholder. As a rendition of Artefact 2 the graphic transformation of geometry will be adjusted to meet the requirements for the micromobility device user set out in Calibration table 1.



**Figure 4.31:** Test 2 Artefact 2.

With the view of improving the performance of Artefact 2 for the micromobility device user stakeholder for the purpose of further testing the system, Test 2 Artefact 2 is an

adjustment to the shapes used and the graphic information attribution. The aim is to eliminate edges and node and increase the count for path and zone.

**Table 4.33: Test 2 Artefact 2 geometry count**

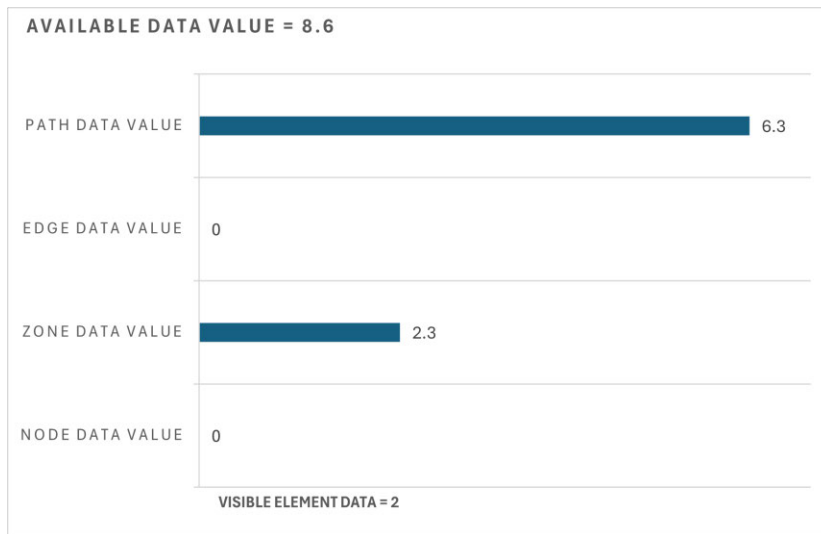
	Shape	Label	Weight
<i>Path-road</i>	U1=2	V1=2	W1=1
<i>Path-motor vehicle</i>	U1=12	V1=4	W1=2
<i>Path-pedestrian</i>	U1=4	V1=8	W1=2
<i>Path-micro device</i>	U1=1	V1=2	W1=2
<i>Edge</i>	0	0	0
<i>Zone-pedestrian</i>	U2=8	0	W2=1
<i>Zone-motor vehicle</i>	U2=1	0	W2=1
<i>Zone-micro device</i>	U2=1	0	W2=1
<i>Node-micro device</i>	0	0	0

**TEST 2 ARTEFACT 2 SYSTEM ANALYSIS:**

Although the Visible Element Data is also = 2, the same as Artefact 2, the Available Data Value is increased slightly compared to Artefact 2.

The System Analysis for the Test 2 Artefact 2 in Experiment 2 shows:

**Table 4.34: Test 2 Artefact 2 Analysis Summary**



**TEST 2 ARTEFACT 2 SYSTEM EVALUATION:**

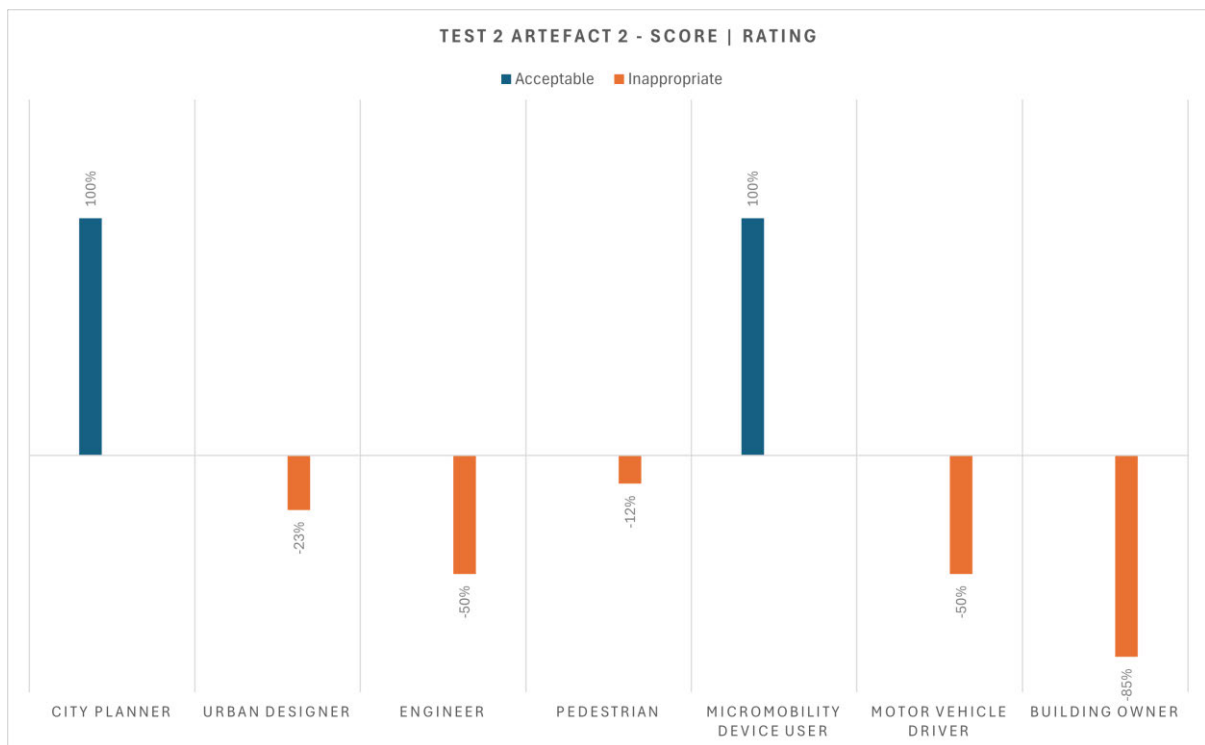
The System Evaluation for the Test 2 Artefact 2 in Experiment 2:

The system evaluated the artefact's statistical data analysis against the requirements set out for individual stakeholders. The system produced an autogenerated result as shown in the evaluation table in Sub-Section 4.3.8 for Test 2 Artefact 2 Evaluation.

The table shows the result of the evaluation for Test 2 Artefact 2 which results in a great improvement on the performance of the artefact for micromobility device user stakeholder with a score increase from 76% Inappropriate to 100% Acceptable.


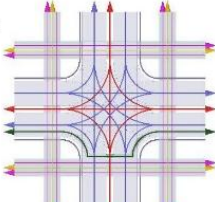
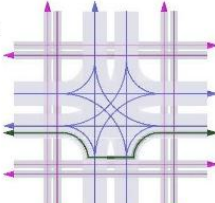
Based on the Available Data Value = 8.6, and the Visible Element Data = 2 of Test 2 Artefact 2, the summary of the Result is shown in the chart below for the artefact's score and rating for each stakeholder:

**Table 4.35: Test 2 Artefact 2 Evaluation Summary**



### 4.3.7 PERFORMANCE RESULTS

This Sub-Section shows the results for Experiment 2. The results for artefact graphic comparison and the score and ranking for each for *urban designer* and for *micromobility device user* based on the parameters set out in Calibration tables 1 and 2 and the computation set out in Calibration table 3 are shown below. As well the overall results summary for Experiment 2 is summarised in the chart below and the overall performance comparison are set out below to illustrate the percentage data value and the percentage data failure for all three artefacts in Experiment 2.

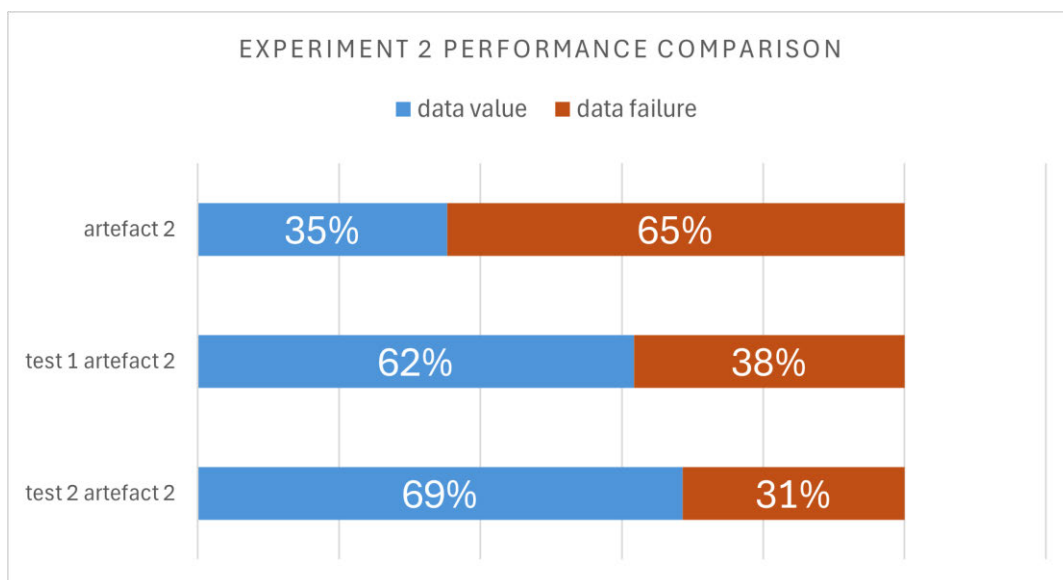
EXPERIMENT 2		urban designer	micromobility device user
ARTEFACT 2		7% Inappropriate	62% Inappropriate
TEST 1 ARTEFACT 2		<b>100%</b> <b>Acceptable</b>	26% Inappropriate
TEST 2 ARTEFACT 2		6% Inappropriate	<b>100%</b> <b>Acceptable</b>

**Figure 4.32:** Results Comparison for urban designer and micromobility device user

**Table 4.36: Experiment 2 Results Summary**




**Table 4.37: Experiment 2 Artefacts Performance Results**



### 4.3.8 ANALYSIS & EVALUATION TABLES

#### ARTEFACT 2 ANALYSIS & EVALUATION

Table 4.38: Artefact 2 Analysis



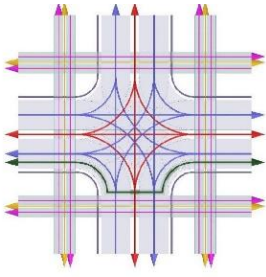
urban object	urban element	parameter	ANALYSIS shape				drawing #2 label				weight				Sum		
			u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3			
			point	line/ curve	plane	solid	text/ number/ symbol	line/ curve	plane	solid	point area	thickn ess/ colour	hatch/ colour	hatch/ colour			
0	road	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
0	motor vehicle	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
0	pedestrian	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
0	micromobility d path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
0	0																0.0 PATH DATA VALUE
1	road	edge	visibility	0	1	0	0	0	0	0	0	0	1	0	0	0	2.1
			count	0	9	0	0	0	0	0	0	0	3	0	0	0	2.1
			amount	0	1.8	0	0	0	0	0	0	0.3	0	0	0	0	2.1
1	pedestrian	edge	visibility	0	1	1	0	0	0	0	0	0	1	1	0	0	2.0
			count	0	7	2	0	0	0	0	0	0	1	1	0	0	2.0
			amount	0	1.4	0.4	0	0	0	0	0	0.1	0.1	0	0	0	2.0
1	micromobility d edge	visibility	0	1	0	0	0	0	0	0	0	1	0	0	0	1.3	
			count	0	6	0	0	0	0	0	0	1	0	0	0	1.3	
			amount	0	1.2	0	0	0	0	0	0	0.1	0	0	0	0	1.3
1	3																5.4 EDGE DATA VALUE
1	pedestrian	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	0	1.0
			count	0	0	3	0	0	0	3	0	0	0	1	0	0	1.0
			amount	0	0	0.6	0	0	0	0.3	0	0	0	0.1	0	0	1.0
1	motor vehicle	zone	visibility	0	1	0	0	0	0	1	0	0	1	0	0	0	2.7
			count	0	10	0	0	0	0	3	0	0	4	0	0	0	2.7
			amount	0	2	0	0	0	0	0.3	0	0	0.4	0	0	0	2.7
1	micromobility d zone	visibility	0	0	1	0	0	0	0	0	0	0	1	0	0	0.7	
			count	0	0	3	0	0	0	0	0	0	1	0	0	0.7	
			amount	0	0	0.6	0	0	0	0	0	0	0.1	0	0	0	0.7
1	3																4.4 ZONE DATA VALUE
0	micromobility d node	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
0	0																0.0 NODE DATA VALUE
0	micromobility d landmark	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
0	0																0.0 LANDMARK DATA VALUE
0	micromobility d district	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
0	0																0.0 DISTRICT DATA VALUE
2	VISIBLE ELEMENT DATA														9.8	AVAILABLE DATA VALUE	
4	REQUIRED ANALYSED DATA																

**Table 4.39: Artefact 2 Evaluation**

EVALUATION															
System calculates:															
urban object-urban element	urban element visibility	city planner		urban designer		engineer		pedestrian		micromobility device user		motor vehicle driver	building owner		
road-path	0	-1		-1		-1		-1		-1		-1		0	
motor vehicle-path	0	-1		-1		-1		-1		-1		-1		0	
pedestrian-path	0	-1		-1		-1		-1		-1		-1		0	
micromobility device-path	0	-1		-1		-1		-1		-1		-1		0	
DATA PENALTY		-1		-1		-1		-1		-1		-1		0	
PATH DATA VALUE LESS PENALTY			-1		-1		-1		-1		-1		-1		0
ELEMENT PENALTY		-1		-1		-1		-1		-1		-1		0	
road-edge	1	-1		0		0		-1		-1		0		-1	
pedestrian-edge	1	-1		0		0		-1		-1		0		-1	
micromobility device-edge	1	-1		0		0		-1		-1		0		-1	
DATA PENALTY		-3		0		0		-3		-3		0		-3	
EDGE DATA VALUE LESS PENALTY			-1		5.4		5.4		-1		-1		5.4		-1
ELEMENT PENALTY		-1		0		0		-1		-1		0		-1	
pedestrian-zone	1	0		0		-1		0		0		-1		0	
motor vehicle-zone	1	0		0		-1		0		0		-1		0	
micromobility device-zone	1	0		0		-1		0		0		-1		0	
DATA PENALTY		0		0		-3		0		0		-3		0	
ZONE DATA VALUE LESS PENALTY			4.4		4.4		-1		4.4		4.4		-1		4.4
ELEMENT PENALTY		0		0		-1		0		0		-1		0	
micromobility device-node	0	0		-1		0		-1		0		0		0	
DATA PENALTY		0		-1		0		-1		0		0		0	
NODE DATA VALUE LESS PENALTY			0		-1		0		-1		0		0		0
ELEMENT PENALTY		0		-1		0		-1		0		0		0	
micromobility device-landmark	0	0		0		0		0		0		0		0	
DATA PENALTY		0		0		0		0		0		0		0	
LANDMARK DATA VALUE LESS PENALTY			0		0		0		0		0		0		0
ELEMENT PENALTY		0		0		0		0		0		0		0	
micromobility device-district	0	0		0		0		0		0		0		0	
DATA PENALTY		0		0		0		0		0		0		0	
DISTRICT DATA VALUE LESS PENALTY			0		0		0		0		0		0		0
ELEMENT PENALTY		0		0		0		0		0		0		0	
<b>SCORING</b>															
<b>STAKEHOLDER DATA VALUE</b>		2.4		7.8		3.4		1.4		2.4		3.4		3.4	
<b>VALUABLE DATA</b>		24%		80%		35%		14%		24%		35%		35%	
<b>RATING</b>															
<b>REQUIRED ELEMENT DATA</b>		2		4		2		3		2		2		1	
<b>TOTAL ELEMENT PENALTY</b>		-2		-2		-2		-3		-2		-2		-1	
<b>ELEMENT DATA FAILURE</b>		50%		50%		50%		75%		50%		50%		25%	
<b>Rated As:</b>		Inappropriate		Inappropriate		Inappropriate		Inappropriate		Inappropriate		Inappropriate		Acceptable	
<b>RESULT</b>		76%		20%		65%		86%		76%		65%		35%	
		Inappropriate		Inappropriate		Inappropriate		Inappropriate		Inappropriate		Inappropriate		Acceptable	

# Test 1 Artefact 2 Analysis & Evaluation

Table 4.40: Test 1 Artefact 2 Analysis



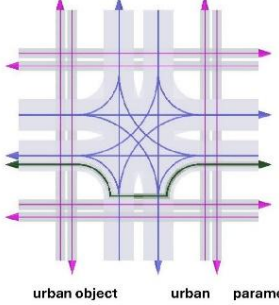
drawing #2	label	weight	ANALYSIS shape				label				weight				Sum	
			u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3		
			point	line/curve	plane	solid	text/number/symbol	line/curve	plane	solid	point area	thickn ess/colour	hatch/colour	hatch/colour		
1	road	path	visibility	0	1	0	0	0	1	0	0	0	1	0	0	1.8
			count	0	6	0	0	0	4	0	0	0	2	0		
			amount	0	1.2	0	0	0	0.4	0	0	0	0.2	0		
1	motor vehicle	path	visibility	0	1	0	0	0	1	0	0	0	1	0	0	3
			count	0	12	0	0	0	4	0	0	0	2	0		
			amount	0	2.4	0	0	0	0.4	0	0	0	0.2	0		
1	pedestrian	path	visibility	0	1	0	0	0	1	0	0	0	1	1	0	4.2
			count	0	12	0	0	0	16	0	0	0	2	0		
			amount	0	2.4	0	0	0	1.6	0	0	0	0.2	0		
1	micromobility device	path	visibility	0	1	0	0	0	1	0	0	0	1	0	0	0.6
			count	0	1	0	0	0	2	0	0	0	2	0		
			amount	0	0.2	0	0	0	0.2	0	0	0	0.2	0		
1	4															9.6 PATH DATA VALUE
1	road	edge	visibility	0	1	0	0	0	0	0	0	0	1	0	0	1
			count	0	4	0	0	0	0	0	0	0	2	0		
			amount	0	0.8	0	0	0	0	0	0	0	0.2	0		
1	pedestrian	edge	visibility	0	1	0	0	0	0	0	0	0	1	0	0	3.3
			count	0	16	0	0	0	0	0	0	0	1	0		
			amount	0	3.2	0	0	0	0	0	0	0	0.1	0		
1	micromobility device	edge	visibility	0	1	0	0	0	0	0	0	0	1	0	0	0.5
			count	0	2	0	0	0	0	0	0	0	1	0		
			amount	0	0.4	0	0	0	0	0	0	0	0.1	0		
1	3															4.8 EDGE DATA VALUE
1	pedestrian	zone	visibility	0	0	1	0	0	0	0	0	0	0	1	0	1.7
			count	0	0	8	0	0	0	0	0	0	0	1	0	
			amount	0	0	1.6	0	0	0	0	0	0	0	0.1	0	
1	motor vehicle	zone	visibility	0	0	1	0	0	0	0	0	0	0	1	0	1.7
			count	0	0	8	0	0	0	0	0	0	0	1	0	
			amount	0	0	1.6	0	0	0	0	0	0	0	0.1	0	
1	micromobility device	zone	visibility	0	0	1	0	0	0	0	0	0	0	1	0	0.3
			count	0	0	1	0	0	0	0	0	0	0	1	0	
			amount	0	0	0.2	0	0	0	0	0	0	0	0.1	0	
1	3															3.7 ZONE DATA VALUE
1	micromobility device	node	visibility	1	0	0	0	0	0	0	0	1	0	0	0	0.2
			count	1	0	0	0	0	0	0	0	2	0	0		
			amount	0.1	0	0	0	0	0	0	0	0.1	0	0		
1	1															0.2 NODE DATA VALUE
0	micromobility device	landmark	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0
			count	0	0	0	0	0	0	0	0	0	0	0		
			amount	0	0	0	0	0	0	0	0	0	0	0		
0	0															0 LANDMARK DATA VALUE
0	micromobility device	district	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0
			count	0	0	0	0	0	0	0	0	0	0	0		
			amount	0	0	0	0	0	0	0	0	0	0	0		
0	0															0 DISTRICT DATA VALUE
4	VISIBLE ELEMENT DATA														18.3	AVAILABLE DATA VALUE
4	REQUIRED ANALYSED DATA															

**Table 4.41: Test 1 Artefact 2 Evaluation**

EVALUATION										
System calculates:										
urban object-urban element	urban element visibility	city planner	urban designer	engineer	pedestrian	micromobility device user	motor vehicle driver	building owner		
road-path	1	0	0	0	0	0	0	0	-1	
motor vehicle-path	1	0	0	0	0	0	0	0	-1	
pedestrian-path	1	0	0	0	0	0	0	0	-1	
micromobility device-path	1	0	0	0	0	0	0	0	-1	
	DATA PENALTY	0	0	0	0	0	0	0	-4	
	PATH DATA VALUE LESS PENALTY	9.6	9.6	9.6	9.6	9.6	9.6	9.6	-1	-1
	ELEMENT PENALTY	0	0	0	0	0	0	0	-1	
road-edge	1	-1	0	0	-1	-1	0	0	-1	
pedestrian-edge	1	-1	0	0	-1	-1	0	0	-1	
micromobility device-edge	1	-1	0	0	-1	-1	0	0	-1	
	DATA PENALTY	-3	0	0	-3	-3	0	0	-3	
	EDGE DATA VALUE LESS PENALTY	-1	4.8	4.8	-1	-1	4.8	4.8	-1	-1
	ELEMENT PENALTY	-1	0	0	-1	-1	0	0	-1	
pedestrian-zone	1	0	0	-1	0	0	-1	0	0	
motor vehicle-zone	1	0	0	-1	0	0	-1	0	0	
micromobility device-zone	1	0	0	-1	0	0	-1	0	0	
	DATA PENALTY	0	0	-3	0	0	-3	0	0	
	ZONE DATA VALUE LESS PENALTY	3.7	3.7	-1	3.7	3.7	-1	-1	3.7	3.7
	ELEMENT PENALTY	0	0	-1	0	0	-1	0	0	
micromobility device-node	1	-1	0	-1	0	-1	-1	-1	-1	
	DATA PENALTY	-1	0	-1	0	-1	-1	-1	-1	
	NODE DATA VALUE LESS PENALTY	-1	0.2	-1	0.2	-1	-1	-1	-1	-1
	ELEMENT PENALTY	-1	0	-1	0	-1	-1	-1	-1	
micromobility device-landmark	0	0	0	0	0	0	0	0	0	
	DATA PENALTY	0	0	0	0	0	0	0	0	
	LANDMARK DATA VALUE LESS PENALTY	0	0	0	0	0	0	0	0	0
	ELEMENT PENALTY	0	0	0	0	0	0	0	0	
micromobility device-district	0	0	0	0	0	0	0	0	0	
	DATA PENALTY	0	0	0	0	0	0	0	0	
	DISTRICT DATA VALUE LESS PENALTY	0	0	0	0	0	0	0	0	0
	ELEMENT PENALTY	0	0	0	0	0	0	0	0	
<b>SCORING</b>										
STAKEHOLDER DATA VALUE VALUABLE DATA		11.3 62%	18.3 100%	12.4 68%	12.5 68%	11.3 62%	12.4 68%	0.7 4%		
<b>RATING</b>										
REQUIRED ELEMENT DATA		2	4	2	3	2	2	1		
TOTAL ELEMENT PENALTY		-2	0	-2	-1	-2	-2	-3		
ELEMENT DATA FAILURE		50%	0%	50%	25%	50%	50%	75%		
Rated As:		Inappropriate	Acceptable	Inappropriate	Acceptable	Inappropriate	Inappropriate	Inappropriate		
<b>RESULT</b>		38% Inappropriate	100% Acceptable	32% Inappropriate	68% Acceptable	38% Inappropriate	32% Inappropriate	96% Inappropriate		

# Test 2 Artefact 2 Analysis & Evaluation

Table 4.42: Test 2 Artefact 2 Analysis



	urban object	urban element	parameter	ANALYSIS shape				drawing #2				label				weight				Sum
				1		1		1		1		1		1		1				
				u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3					
			point	line/curve	plane	solid	text/number/symbol	line/curve	plane	solid	point area	thickn ess/colour	hatch/colour	hatch/colour						
1	road	path	visibility count amount	0 2 0.4	1 0 0	0 0 0	0 0 0	0 4 0.4	1 0 0	0 0 0	0 0 0	0 1 0.1	1 0 0	0 0 0	0.9					
1	motor vehicle	path	visibility count amount	0 12 2.4	1 0 0	0 0 0	0 0 0	0 4 0.4	1 0 0	0 0 0	0 0 0	0 2 0.2	1 0 0	0 0 0	3					
1	pedestrian	path	visibility count amount	0 4 0.8	1 0 0	0 0 0	0 0 0	0 8 0.8	1 0 0	0 0 0	0 0 0	0 2 0.2	1 0 0	0 0 0	1.8					
1	micromobility device	path	visibility count amount	0 1 0.2	1 0 0	0 0 0	0 0 0	0 2 0.2	1 0 0	0 0 0	0 0 0	0 2 0.2	1 0 0	0 0 0	0.6					
4														6.3 PATH DATA VALUE						
0	road	edge	visibility count amount	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0					
0	pedestrian	edge	visibility count amount	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0					
0	micromobility device	edge	visibility count amount	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0					
0														0 EDGE DATA VALUE						
1	pedestrian	zone	visibility count amount	0 0 0	0 8 1.6	1 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	1 1 0.1	0 0 0	1.7					
1	motor vehicle	zone	visibility count amount	0 0 0	0 1 0.2	1 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	1 1 0.1	0 0 0	0.3					
1	micromobility device	zone	visibility count amount	0 0 0	0 1 0.2	1 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	1 1 0.1	0 0 0	0.3					
3														2.3 ZONE DATA VALUE						
0	micromobility device	node	visibility count amount	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0					
0														0 NODE DATA VALUE						
0	micromobility device	landmark	visibility count amount	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0					
0														0 LANDMARK DATA VALUE						
0	micromobility device	district	visibility count amount	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0					
0														0 DISTRICT DATA VALUE						
2	VISIBLE ELEMENT DATA														8.6 AVAILABLE DATA VALUE					
4	REQUIRED ANALYSED DATA																			

**Table 4.43: Test 2-Artifact 2 Evaluation**

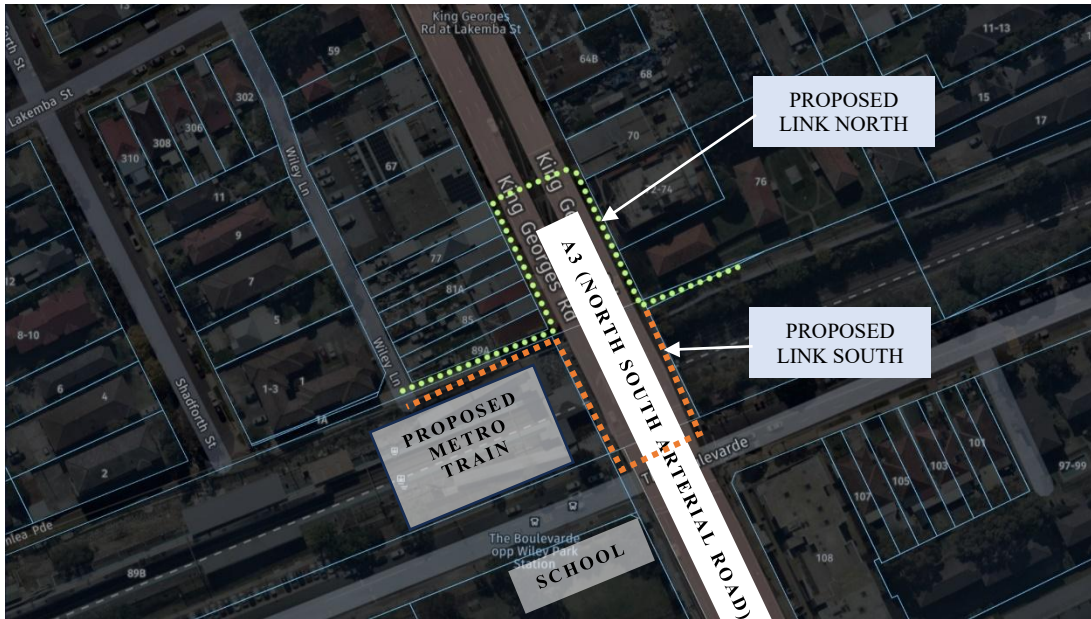
EVALUATION									
System calculates:									
urban object-urban element	urban element visibility	city planner	urban designer	engineer	pedestrian	micromobility device user	motor vehicle driver	building owner	
road-path	1	0	0	0	0	0	0	-1	
motor vehicle-path	1	0	0	0	0	0	0	-1	
pedestrian-path	1	0	0	0	0	0	0	-1	
micromobility device-path	1	0	0	0	0	0	0	-1	
DATA PENALTY		0	0	0	0	0	0	-4	
PATH DATA VALUE LESS PENALTY		6.3	6.3	6.3	6.3	6.3	6.3	-1	
ELEMENT PENALTY		0	0	0	0	0	0	-1	
road-edge	0	0	-1	-1	0	0	-1	0	
pedestrian-edge	0	0	-1	-1	0	0	-1	0	
micromobility device-edge	0	0	-1	-1	0	0	-1	0	
DATA PENALTY		0	-3	-3	0	0	-3	0	
EDGE DATA VALUE LESS PENALTY		0	-1	-1	0	0	-1	0	
ELEMENT PENALTY		0	-1	-1	0	0	-1	0	
pedestrian-zone	1	0	0	-1	0	0	-1	0	
motor vehicle-zone	1	0	0	-1	0	0	-1	0	
micromobility device-zone	1	0	0	-1	0	0	-1	0	
DATA PENALTY		0	0	-3	0	0	-3	0	
ZONE DATA VALUE LESS PENALTY		2.3	2.3	-1	2.3	2.3	-1	2.3	
ELEMENT PENALTY		0	0	-1	0	0	-1	0	
micromobility device-node	0	0	-1	0	-1	0	0	0	
DATA PENALTY		0	-1	0	-1	0	0	0	
NODE DATA VALUE LESS PENALTY		0	-1	0	-1	0	0	0	
ELEMENT PENALTY		0	-1	0	-1	0	0	0	
micromobility device-landmark	0	0	0	0	0	0	0	0	
DATA PENALTY		0	0	0	0	0	0	0	
LANDMARK DATA VALUE LESS PENALTY		0	0	0	0	0	0	0	
ELEMENT PENALTY		0	0	0	0	0	0	0	
micromobility device-district	0	0	0	0	0	0	0	0	
DATA PENALTY		0	0	0	0	0	0	0	
DISTRICT DATA VALUE LESS PENALTY		0	0	0	0	0	0	0	
ELEMENT PENALTY		0	0	0	0	0	0	0	
<b>SCORING</b>									
STAKEHOLDER DATA VALUE		8.6	6.6	4.3	7.6	8.6	4.3	1.3	
VALUABLE DATA		100%	77%	50%	88%	100%	50%	15%	
<b>RATING</b>									
REQUIRED ELEMENT DATA		2	4	2	3	2	2	1	
TOTAL ELEMENT PENALTY		0	-2	-2	-1	0	-2	-1	
ELEMENT DATA FAILURE		0%	50%	50%	25%	0%	50%	25%	
Rated As:		Acceptable	Inappropriate	Inappropriate	Acceptable	Acceptable	Inappropriate	Acceptable	
RESULT		100%	23%	50%	88%	100%	50%	15%	
		Acceptable	Inappropriate	Inappropriate	Acceptable	Acceptable	Inappropriate	Acceptable	

## **4.4 EXPERIMENT 3**

Experiment 3 is an evaluation of three artefacts. The first is Artefact 3. The second is Test 1 Artefact 3 and the third is Test 2 Artefact 3. At the conclusion of the experiment, a comparison of the three results will be presented.

### **4.4.1 BACKGROUND ARTEFACT 3**

Similarly, Artefact 3 involves a cycleway proposal and is a segment of the east west pedestrian and cycling link by Sydney Metro as part of the planning requirement for the delivery of the Southwest Sydney Metro. This project has its own variables due to the complexity of its location and the different key stakeholder groups involved in the area and the technical constraints. The complexity of Project 3 is exacerbated as the proposed cycleway crosses a major north-south metropolitan arterial corridor, which is jointly funded and managed by the local government and the NSW state government. This arterial corridor is a high-capacity busy road designed for motorised vehicle priority and connects to the freeway/motorway. The proposed cycleway will run along parallel to the Metro train line and is perpendicular to the north south arterial corridor. Crossing this busy corridor has many constraints and is a great challenge. As such the image in Figure 4.33 taken from *Nearmap* shows the relevant arterial corridor, the boundaries and town centre context to illustrate the project's significance to road users, pedestrians and the local and business communities. Figure 4.34 shows the Google Street View directly in front of the train station entrance.



**Figure 4.33:** Project 3, cycleway crossing a major metropolitan arterial road



**Figure 4.34:** Google street view. State road corridor northbound.

### Technical Constraints

The arterial road is a vehicle priority busy road. For a cycle route and cyclists to cross this safely would require crossing at the traffic lights. However, to reach the traffic lights north, cyclists will have to travel a total of 90 metres in pedestrian space along shopfronts in a dogleg route.

This space is pedestrian priority and due to its location and the high risk for pedestrians along the arterial road, space allocation requires greater scrutiny to ensure prescribed standards for pedestrian space, safety and levels of service are met. Space along shopfronts has existing trees and street furniture. Buffer zones for pedestrian safety are also required against high vehicle traffic corridors. A south crossing however will require cyclists to pass along the entry and exit point of the Metro train station. This poses high risk of conflict with pedestrians especially during peak hour as the space is insufficient for mixed movement.

#### Conditions and Current Use

The arterial corridor is a busy major connector to the M5 Motorway. The proposed cycling route is adjacent to the Metro train line, and the precinct has fine grain commercial buildings. The proposed north and south crossings are within 100 meters of the entrance to the train station. Due to the train station, the school close by and the commercial precinct the area is generally busy with pedestrians along the arterial road.

#### Future Use and Planned Aspirations

This is also identified as a priority precinct under the Transport Oriented Development program by the NSW state government. New planning controls, delivered through a new State Environment Planning Policy (SEPP) will enable faster delivery of more housing. Under the program, the NSW government will rezone the area to allow for more new and affordable homes. This urban growth means more people is expected in the local area, and the low-rise retail shops will transform into larger scale developments. Walking space is highly constrained; however, a cycleway will also need to be accommodated on the road as part of the planned sustainable future for Sydney.

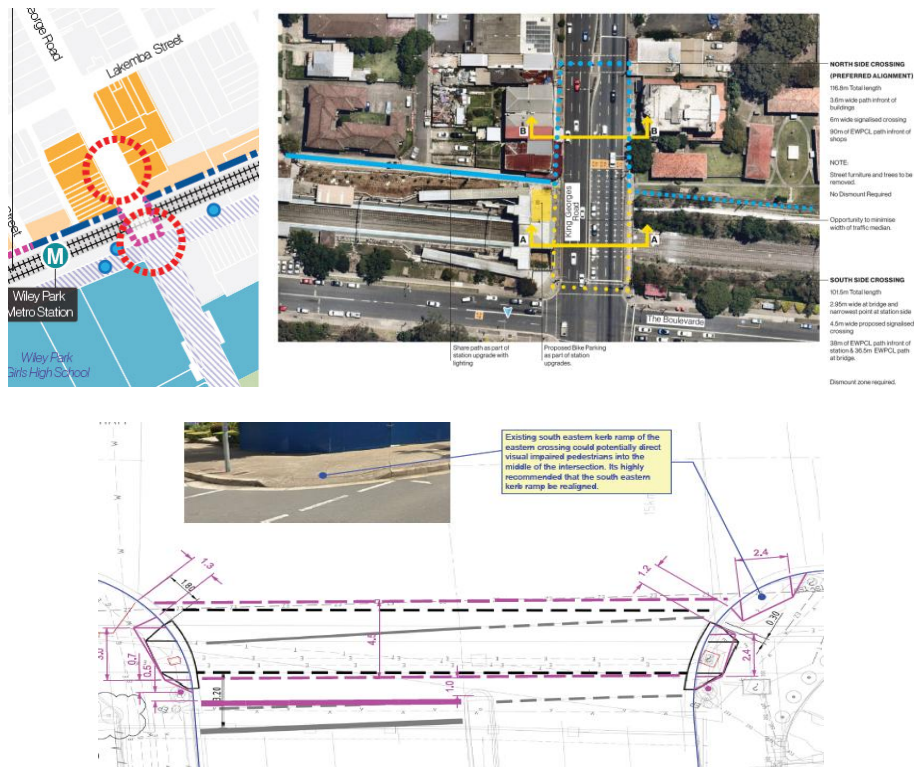


Figure 4.35: Communication artefact samples used.

## THE PROCESS

The design process required multiple site investigations, traffic and movement studies, identification and analysis of physical limitations and opportunities, and other regulatory constraints. The stakeholder technical working group met on a regular basis for the development of preliminary concept designs, reviews, iterative design development. There were workshops and community consultations and a list of activities involving design, planning and coordination.

The technical working group was made up of key stakeholders and met regularly to discuss investigations, studies and design proposals. During the meetings various communication artefacts were used to communicate information relating to design proposals and solution. Constraints, site and technical details, movement issues were examined thoroughly, and concept design iterations were communicated. The artefacts were a critical part of the collaborative process.

### ARTEFACT 3

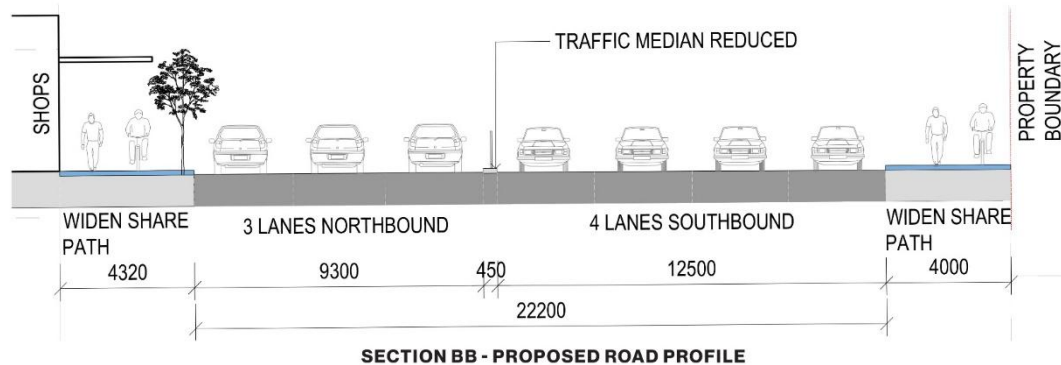


Figure 4.36: Artefact 3.

Typical across all four experiments, communication of movement was also integral in the design process due to the nature of the proposal. The movement of pedestrians, cyclists and motor vehicles were also significant considerations and is vital to the success of the project.

Artefact 3 is a sample of a communication artefact used in this urban design project. This will be analysed and evaluated for Experiment 3. This artefact was chosen as it is different to Artefacts 1 and 2 which are plan views. Artefact 3 is an elevation view of the proposed design. The system will use the same Calibration table values to enable an objective evaluation that uses the same lens regardless of the type of artefact. The same assumptions as well will be adopted. Hence, path will need to be communicated through ways distinct from edge, such as a line or plane in the middle of the road, direction labels or weights to signify a channel for travelling along.

#### 4.4.2 ARTEFACT 3 – LAYERS ANALYSIS



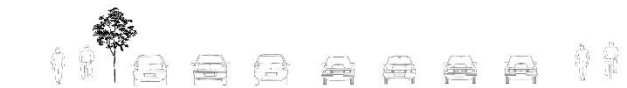
➤ LINES



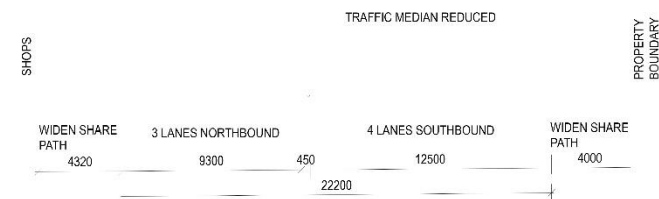
➤ SHADING/ HATCHING



➤ LINEWEIGHTS



➤ ENTOURAGE



➤ ANNOTATIONS

**Figure 4.37:** Artefact 3 Shape Analysis.

Artefact 3 is a 2D communication artefact and is rationalised into layers of information. As such, Artefact 3 is considered to have the following data layers including the shape

geometry of line, and the graphical information attributes of weight such as line weights and hatching or shading, and the graphical information attributes of label such as annotations and entourage.

LINES ANALYSIS | GRAPHIC ALGEBRA:

SHAPE = LINE

ALGEBRA =  $U_{12} W_3$

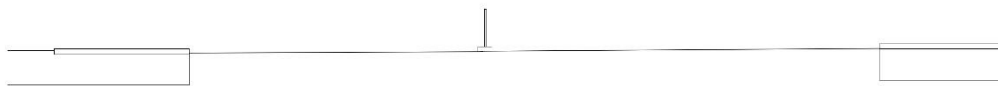
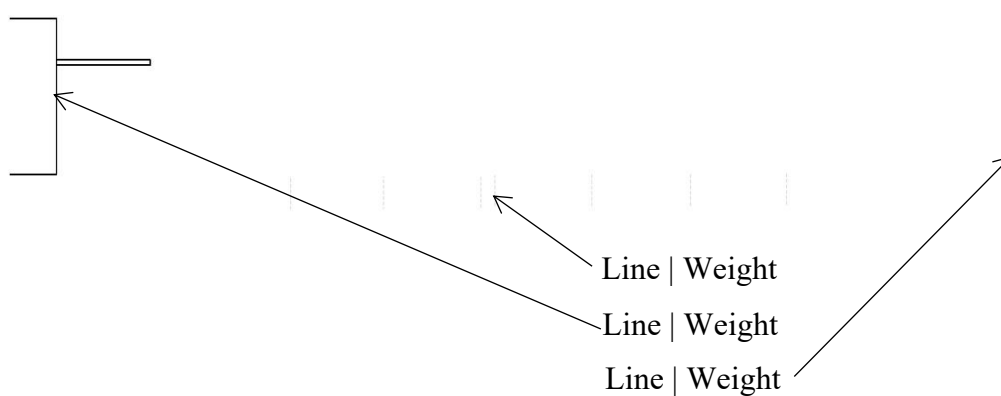


Figure 4.38: Artefact 3 Line Shape Analysis.

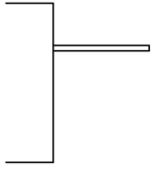


As shown above, the count for line/curve shape is limited compared to Artefacts 1 and 2. The weight graphical attributions shown below used lines/curves and planes shape geometries.

LINEWEIGHTS | WEIGHTS



## Graphic Weights Algebra

Table 4.44: Artefact 3 Line Weight Analysis

	SHAPE: LINE   WEIGHTS	ALGEBRA
1		$U_{12} W_1$
2		$U_{11} W_1$
3		$U_{11} W_1$

## HATCHING/ PLANE WEIGHTS ANALYSIS | GRAPHIC WEIGHTS

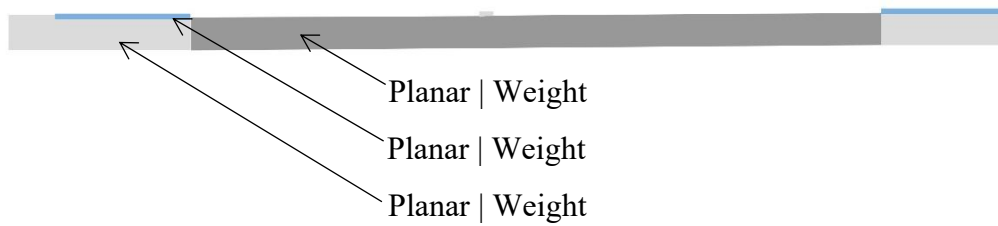





Figure 4.39: Artefact 3 Plane Weights Analysis.

## Graphic Weights Algebra

Table 4.45: Artefact 3 Plane Weights List

	SHAPE: PLANE   WEIGHTS	ALGEBRA
1		$U_{22} W_2$
2		$U_{22} W_2$
3		$U_{22} W_2$

A note on this, the blue plane may also be regarded as a line with weight such as colour and thickness. However, for this research, this will be regarded as plane with weight. The distinction of this is only critical if Calibration table 3 indicates a different computational value for line shape geometry and plane shape geometry. As Calibration table 3 shows the same value for line  $U_1$  shape geometry at 20% and plane  $U_2$  shape geometry at 20%, the calculation will be the same.

### Labels Analysis | Graphic Algebra:

#### Entourage | Labels

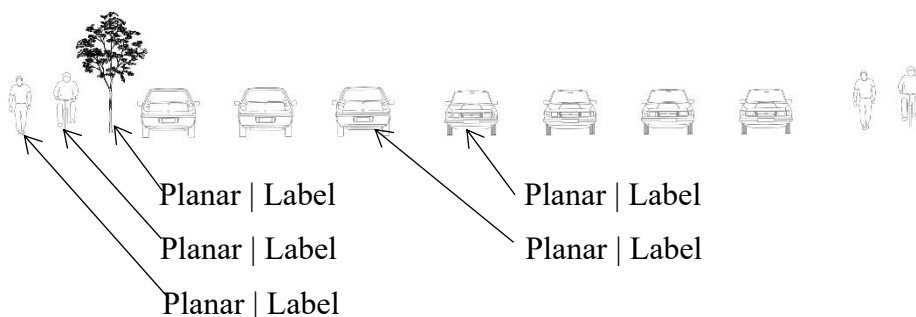







Figure 4.40: Artefact 3 Plane Labels Analysis.

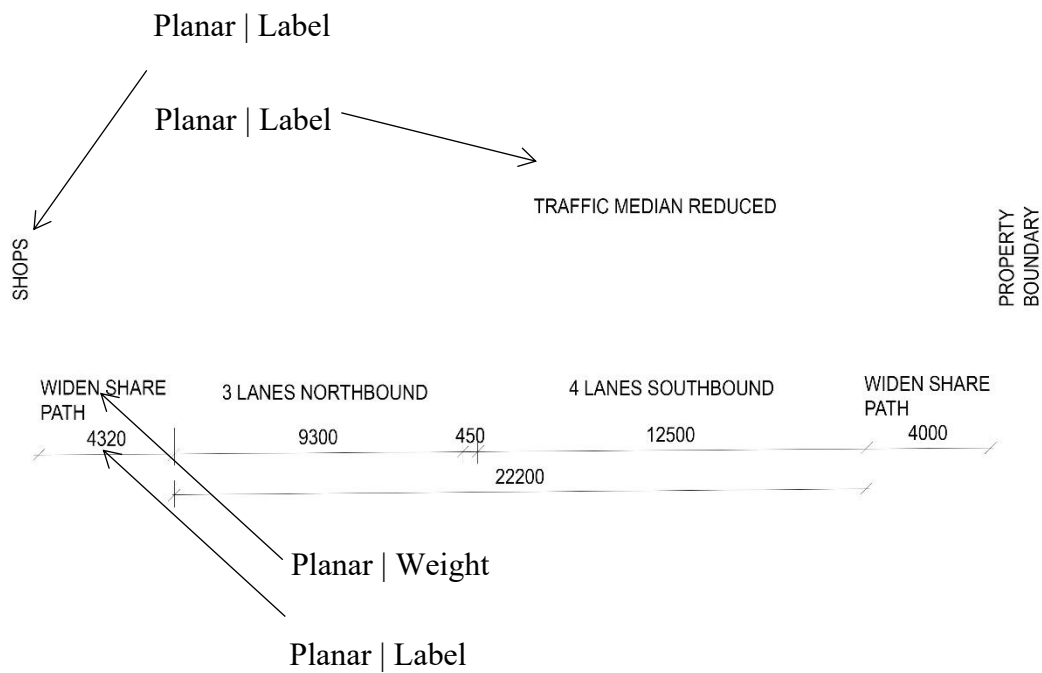
## Graphic Labels | Algebra

Table 4.46: Artefact 3 Plane Labels List

	LABELS	ALGEBRA
1		$U_{01} V_1$
2		$U_{01} V_1$
3		$U_{00} V_2$
4		$U_{01} V_1$
5		$U_{01} V_1$

As shown above, entourage can be considered labels as in this case, the cars show direction. One car type is a rear view and another one a front view. Similarly with pedestrians, they function like arrows to indicate direction.

## ANNOTATIONS | LABEL SETS



**Figure 4.41:** Artefact 3 Plane Label Sets Analysis.

## Graphic Labels Algebra

**Table 4.47:** Artefact 3 Plane Labels Sets

1	LABEL SET 1	ALGEBRA
		$U_{11} V_2$
2	LABEL SET 2	
	WIDEN SHARE PATH	$U_{22} V_2$
	3 LANES NORTHBOUND	$U_{11} V_2$
	TRAFFIC MEDIAN REDUCED	$U_{11} V_2$

	PROPERTY BOUNDARY	$U_{2.2} V_1$
	SHOPS	$U_{1.1} V_2$

As shown above, all dimensions are collectively a label set. As well, text annotations are in sets. A note on the type of annotation, if a text spells out a direction, it can also be considered a separate label. Hence, northbound and southbound can be considered separate labels.

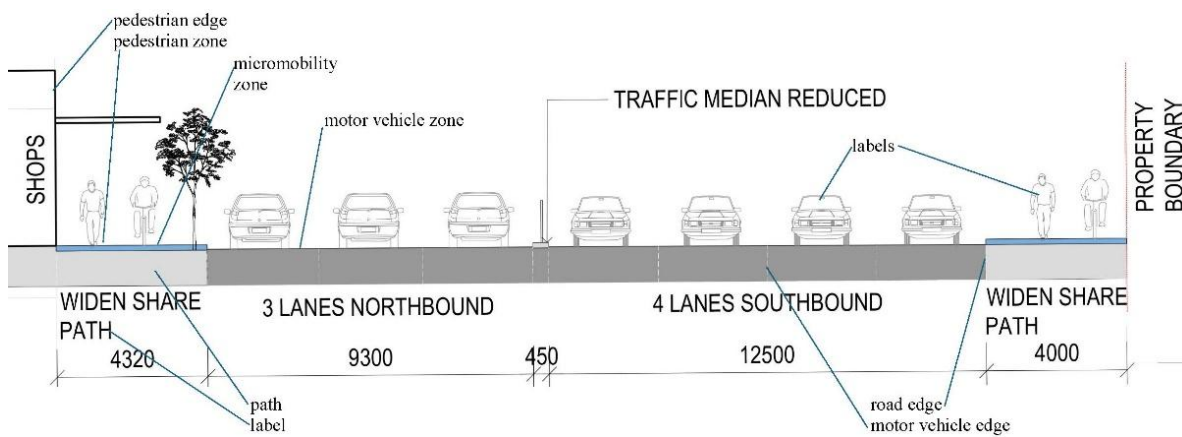


Figure 4.42: Artefact 3, recognising urban objects and urban elements.

### 4.4.3 ARTEFACT 3 – STATISTICAL ANALYSIS

<b>Road straight path</b>	<b>Road straight paths and node</b>	<b>Road and road median</b>
U1 2 (line on 2D space)		U1 2 (line)
	U1 2 (line on 2D space)	U0 2 (point)
	U0 2 (point on 2D space)	
<b>Road, median and road height</b>	<b>Road surface material</b>	<b>Adjacent pedestrian space</b>
U1 2 (line)	U1 2 (line)	U1 2 (line)
U0 2 (point)	U0 2 (point)	U0 2 (point)
	W2 2 (grey)	W2 2 (grey)
<b>Pedestrian footpath height</b>	<b>Pedestrian surface material</b>	<b>Footpath boundary</b>
U1 2 (line)	U1 2 (line)	U1 2 (line)
U0 2 (point)	U0 2 (point)	U0 2 (point)
W2 2 (grey)	W2 2 (grey, purple)	W2 2 (grey, purple)



**Road lanes**

U1 2 (line)

U0 2 (point)

W1 2 (blue)

W2 2 (grey, purple)



**Southbound traffic**

U1 2 (line)

U0 2 (point)

V2 1 (car front)

W1 2 (blue)

W2 2 (grey, purple)



**Northbound and southbound traffic**

U1 2 (line)

U0 2 (point)

V2 1 (cars front/back)

W1 2 (blue)

W2 2 (grey, purple)



**Tree location**

U1 2 (line)

U0 2 (point)

V2 1 (cars front/back)

W1 2 (blue)

W2 2 (grey, purple)



**Tree diameter**

U1 2 (line)

U0 2 (point)

V2 1 (cars front/back)

W1 2 (blue)

W2 2 (grey, purple)



**Tree canopy**

U1 2 (line)

U0 2 (point)

V2 1 (cars front/back)

W1 2 (blue)

W2 2 (grey, purple, green)



**Pedestrian space**

U1 2 (line)

U0 2 (point)

V2 0 (pedestrian)



**Cyclist space**

U1 2 (line)

U0 2 (point)

V2 0 (pedestrian, cyclist)

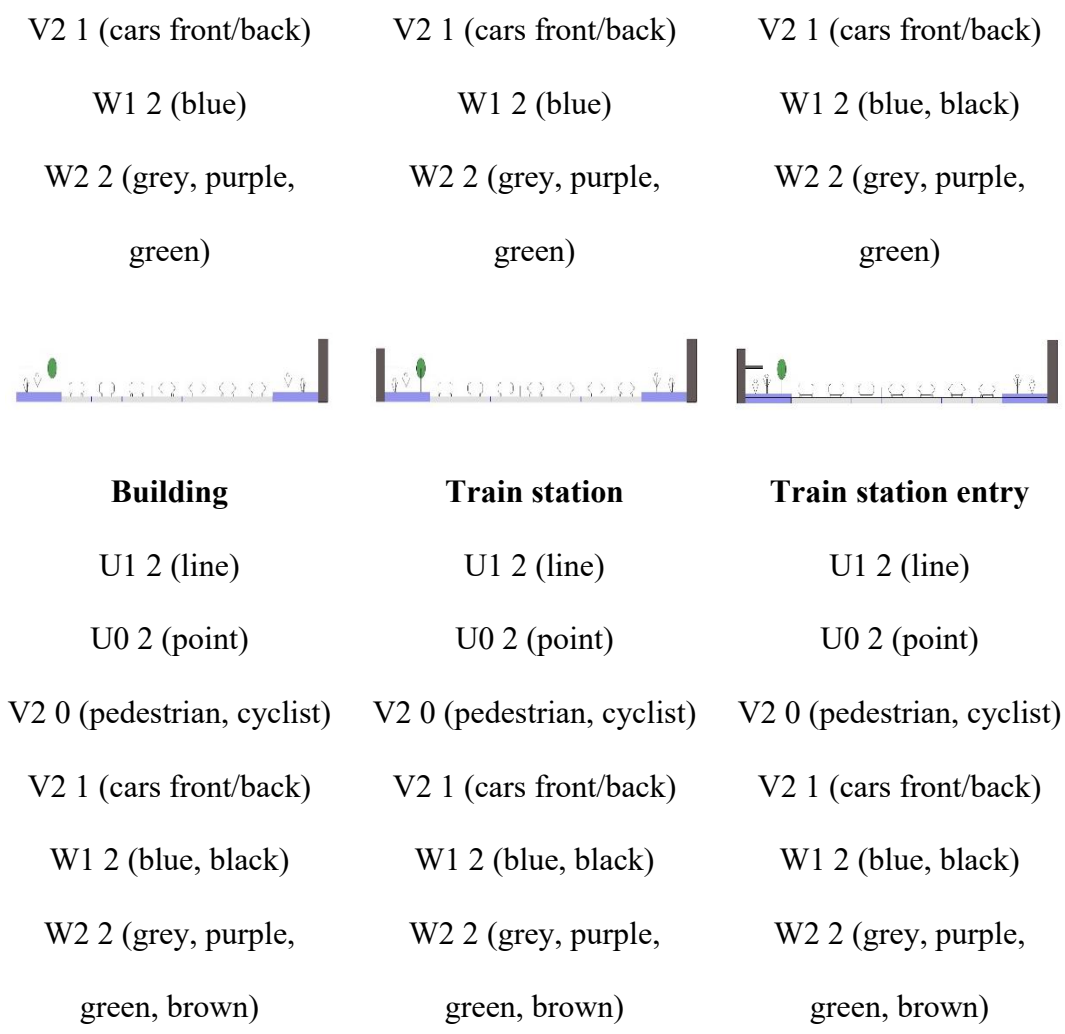


**Median strip rail**

U1 2 (line)

U0 2 (point)

V2 0 (pedestrian, cyclist)



**Figure 4.43:** Artefact 3 geometric transformation analysis.

#### 4.4.4 ARTEFACT 3 - ARTEFACT ANALYSIS & EVALUATION

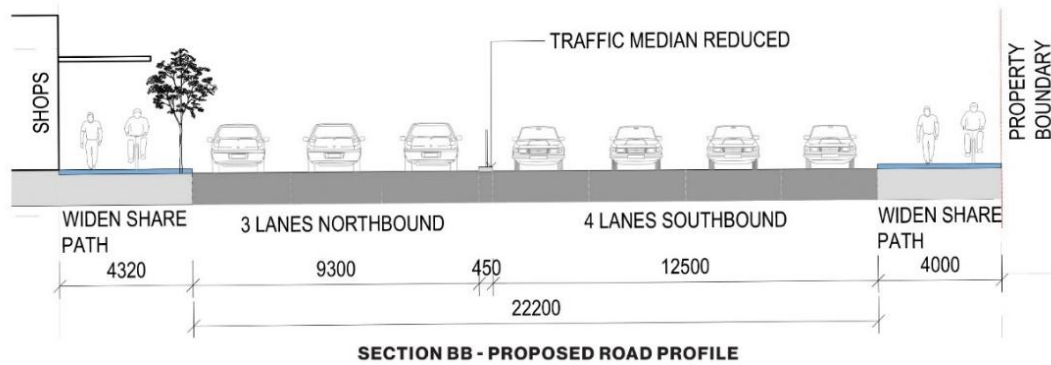


Figure 4.44: Artefact 3.

Table 4.48: Artefact 3 geometry count

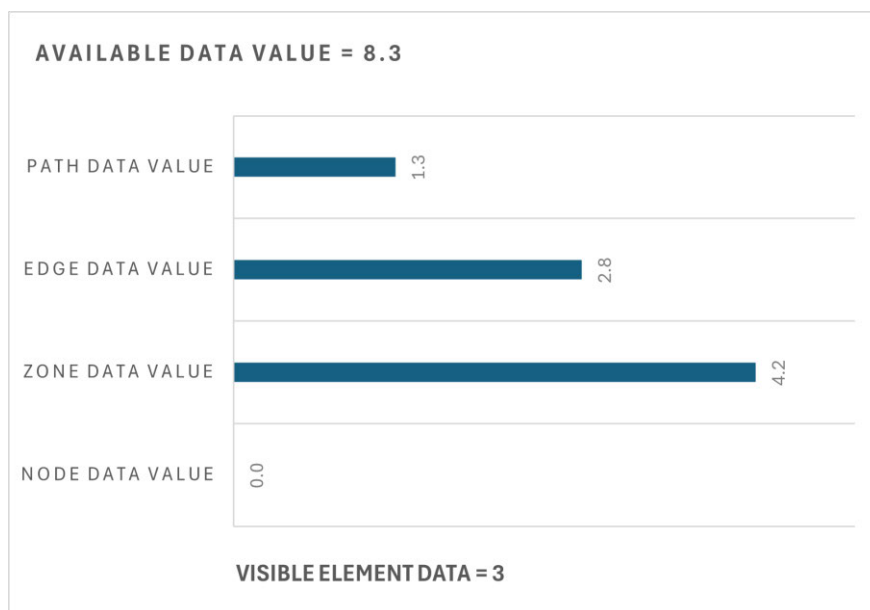
	Shape	Label	Weight
<i>Path-road</i>	0	0	0
<i>Path-motor vehicle</i>	0	0	0
<i>Path-pedestrian</i>	U2=2	V2=2	W2=1
<i>Path-micro device</i>	U2=2	V2=1	W2=1
<i>Edge-road</i>	U1=2	0	0
<i>Edge-pedestrian</i>	U1=4	V1=2	W1=2
<i>Edge-micro device</i>	U1=4	V1=2	W1=2
<i>Zone-pedestrian</i>	U2=2	V2=4	W2=1
<i>Zone-motor vehicle</i>	U2=7	V2=9	W2=1
<i>Zone-micro device</i>	U2=2	V2=4	W2=1
<i>Node-micro device</i>	0	0	0

### Artefact 3 System Analysis:

Based on the graphical layers analysis, the system calculated the graphical statistics and calculated the values based on Calibration table 3.

The Available Data Value is 8.3 which is the total value of the artefact based on the visible urban elements combined. The system also calculated the number of urban elements in the artefact. Artefact 3 has a total of 3 elements, path, edge and zone (Visible Element Data). The analysis for Artefact 3 in Experiment 3 shown in the tables in Sub-Section 4.4.8 and the summary breakdown of the data values are shown below:

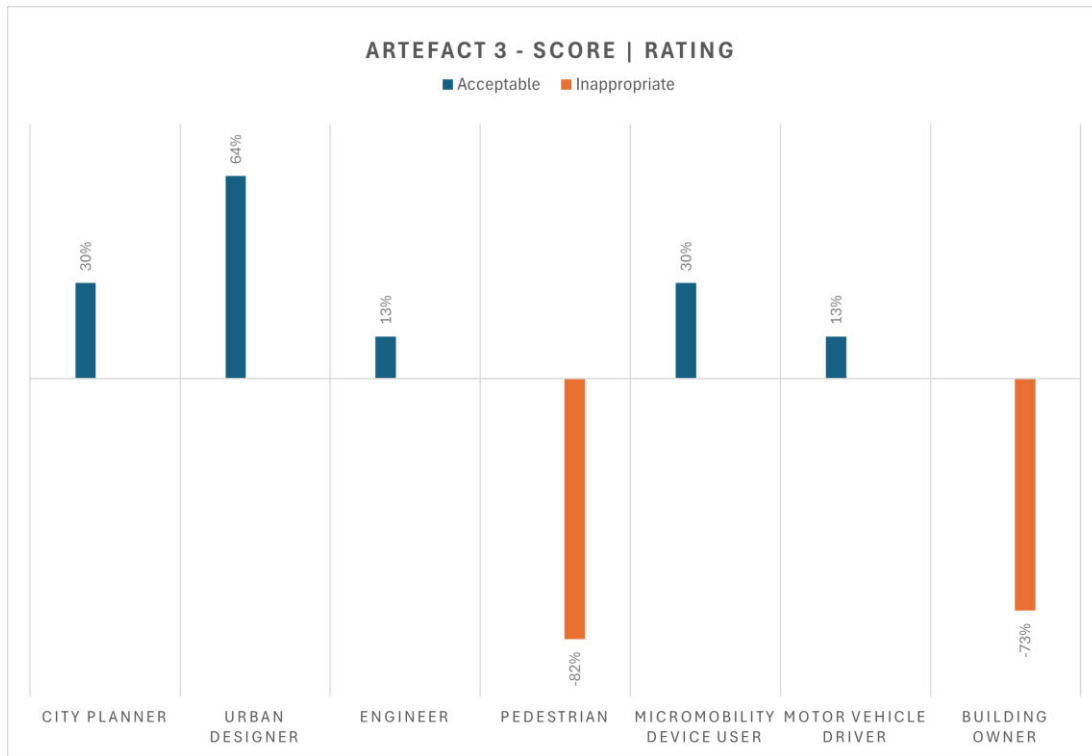
**Table 4.49: Artefact 3 Analysis Summary**



As can be seen in the chart above, node data is zero. As well the urban elements of landmark and district have been turned off to avoid bias. These data values are automated inputs to the evaluation phase 2 of the system for Artefact 3.

### Artefact 3 System Evaluation:

Table 4.50: Artefact 3 Evaluation Summary



The chart above shows the summary of artefact evaluation against stakeholders' requirements set out in Calibration Table 1. Based on the given artefact and the parameters set out in Calibration Table 2, the artefact was measured with a Score and a Rating. The blue bars mean the artefact is acceptable to city planner, urban designer, engineer, micromobility device user and motor vehicle driver stakeholder, whilst the orange bars mean the artefact is inappropriate to pedestrian and building owner stakeholders.

As such, based on the Available Data Value = 8.3, and the Visible Element Data = 3 of Artefact 3, the Result shows the artefact's score and rating for each stakeholder in the table shown in Sub-Section 4.4.8.

#### 4.4.5 TEST 1 – Artefact 3

Test 1 Artefact 2 presents a variation to the graphical data in Artefact 3 and is customised to improve its performance for the *urban designer* stakeholder based on Calibration Table 1. The test artefact is a rendition of Artefact 3 to demonstrate the graphic transformation of geometry based on the original artefact geometry.

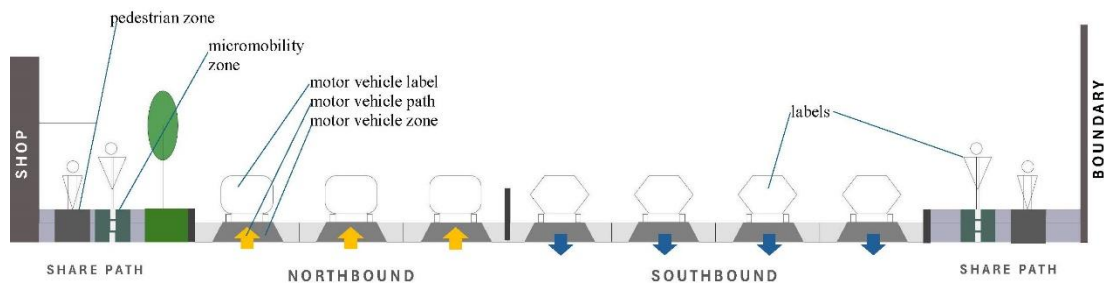


Figure 4.45: Test 1-Artefact 3.

Table 4.51: Test 1 Artefact 2 geometry count

	Shape	Label	Weight
<i>Path-road</i>	U1=6	V1=4	W1=2
<i>Path-motor vehicle</i>	U1=12	V1=4	W1=2
<i>Path-pedestrian</i>	U1=12	V1=16	W1=2
<i>Path-micro device</i>	U1=1	V1=2	W1=2
<i>Edge-road</i>	U1=4	0	W1=2
<i>Edge-pedestrian</i>	U1=16	0	W1=1

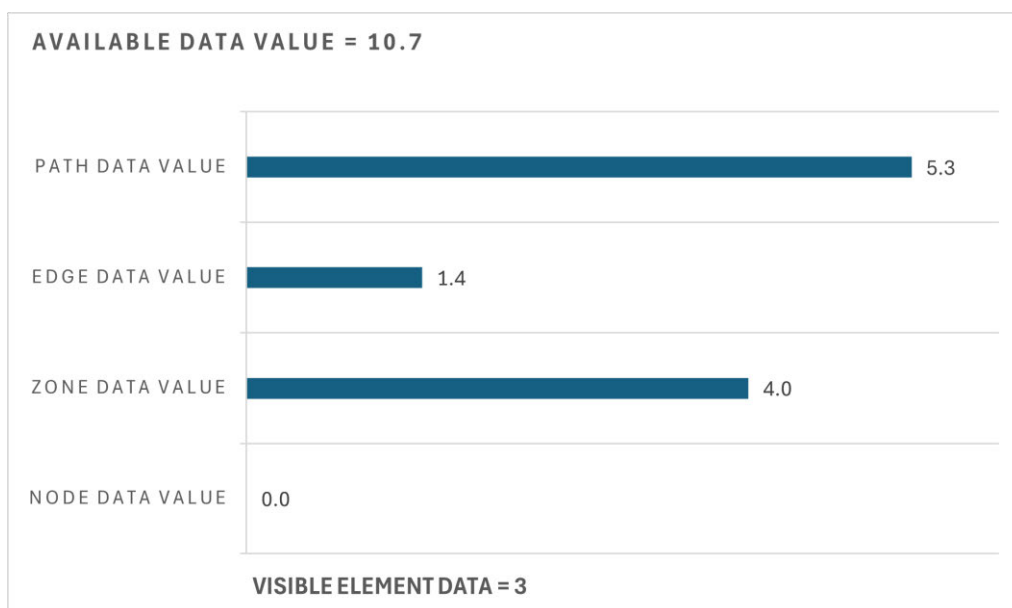
<i>Edge-micro device</i>	U1=2	0	W1=1
<i>Zone-pedestrian</i>	U2=8	0	W2=1
<i>Zone-motor vehicle</i>	U2=8	0	W2=1
<i>Zone-micro device</i>	U2=1	0	W2=1
<i>Node-micro device</i>	U0=1	0	W0=2

### Test 1 Artefact 3 System Analysis:

The above table shows the geometry count for Test 1 Artefact 3. The result summary of the analysis for Test 1 Artefact 3 is shown below which shows that node still has not been added. Path data increased however edge and zone data decreased in data values compared to Artefact 3 analysis. The analysis table is Sub-Section 4.4.8.

The System Analysis for the Test 1 Artefact 3 in Experiment 3 shows:

**Table 4.52: Test 1 Artefact 3 Analysis Summary**



## TEST 1 ARTEFACT 3 SYSTEM EVALUATION:

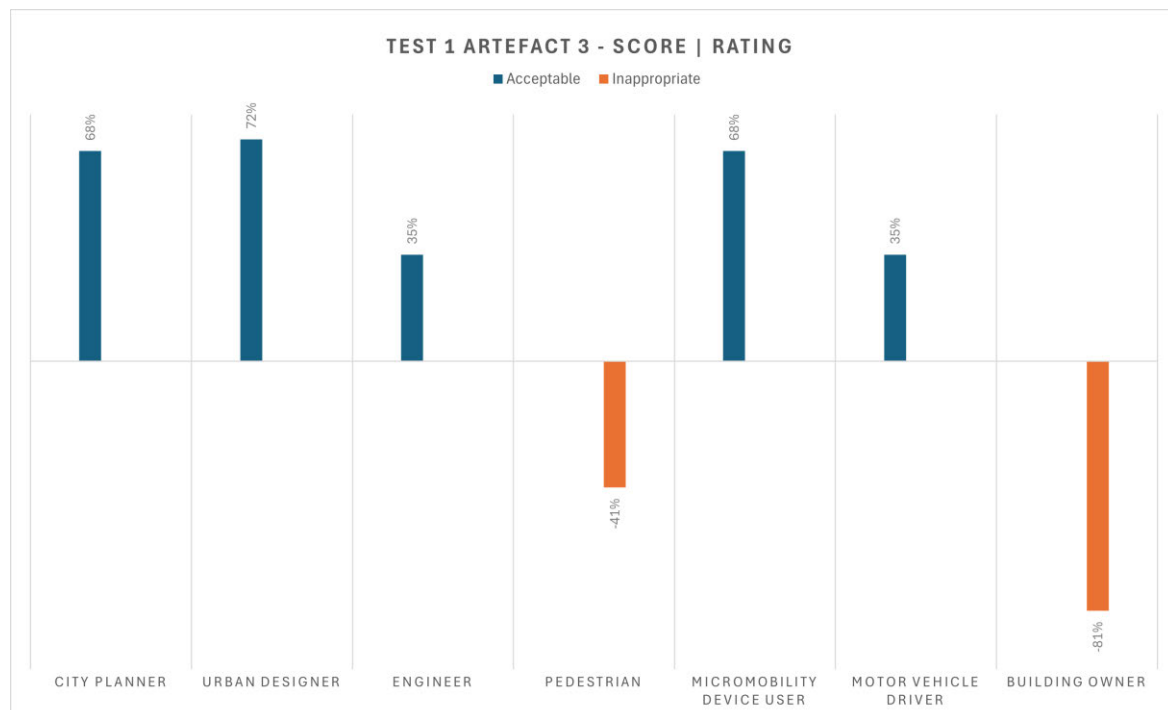
The System Evaluation for the Test 1-Artefact 3 in Experiment 3 shows:

The system evaluated the artefact's statistical data analysis against the requirements set out for individual stakeholders. The system produced an autogenerated result as shown in the evaluation table in Sub-Section 4.4.8 for Test 1-Artefact 3 Evaluation.

The table shows the result of the evaluation for Test 1 Artefact 3 which shows a score of 72% Acceptability, an improvement on the performance of the artefact for urban designer. It also kept the same ratings of acceptable and inappropriate but resulting an improvement on the scores for all stakeholders.

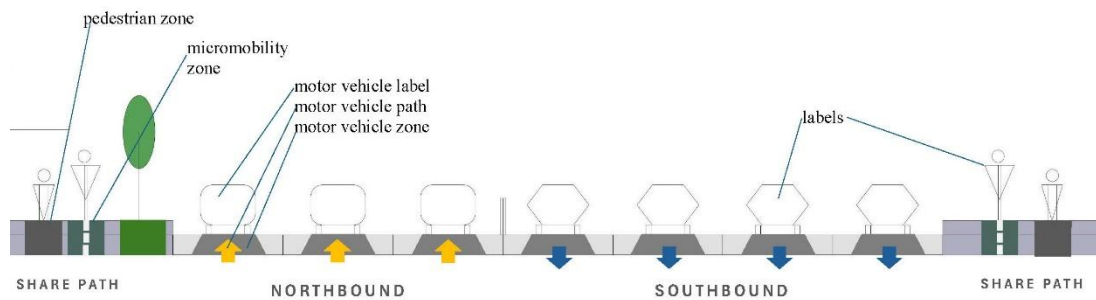
Based on the Available Data Value = 10.7, and the Visible Element Data = 3 of Test 1-Artefact 3, the summary of the Result is shown in the chart below for the artefact's score and rating for each stakeholder:

**Table 4.53: Test 1 Artefact 3 Evaluation Summary**



#### 4.4.6 TEST 2 – Artefact 3

Test 2 Artefact 3 also presents another variation to the graphical data in Artefact 3 and is customised to improve its performance for the micromobility device user stakeholder. As a rendition of Artefact 3 the graphic transformation of geometry will be adjusted to meet the requirements for the micromobility device user set out in Calibration table 1.



**Figure 4.46:** Test 2-Artefact 3.

With the view of improving the performance of Artefact 3 for the micromobility device user stakeholder, Test 2 Artefact 3 is an adjustment to the shapes used and the graphic information attribution. The aim is to eliminate edges and node and increase the count for path and zone.

**Table 4.54: Test 2 Artefact 3 geometry count**

	Shape	Label	Weight
<i>Path-road</i>	U1=2	V1=2	W1=1
<i>Path-motor vehicle</i>	U1=12	V1=4	W1=2
<i>Path-pedestrian</i>	U1=4	V1=8	W1=2

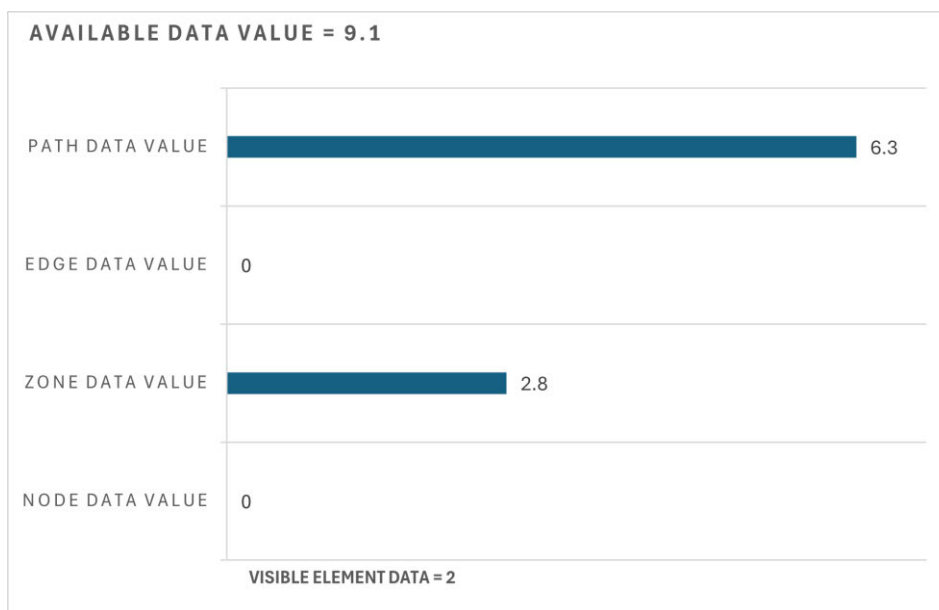
<i>Path-micro device</i>	U1=1	V1=2	W1=2
<i>Edge</i>	0	0	0
<i>Zone-pedestrian</i>	U2=8	0	W2=1
<i>Zone-motor vehicle</i>	U2=1	0	W2=1
<i>Zone-micro device</i>	U2=1	0	W2=1
<i>Node-micro device</i>	0	0	0

**TEST 2 ARTEFACT 3 SYSTEM ANALYSIS:**

Although the Visible Element Data is = 2, the Available Data Value is increased slightly compared to Artefact 3.

The System Analysis for the Test 2 Artefact 3 in Experiment 3:

**Table 4.55: Test 2 Artefact 3 Analysis Summary**



## TEST 2 ARTEFACT 3 SYSTEM EVALUATION:

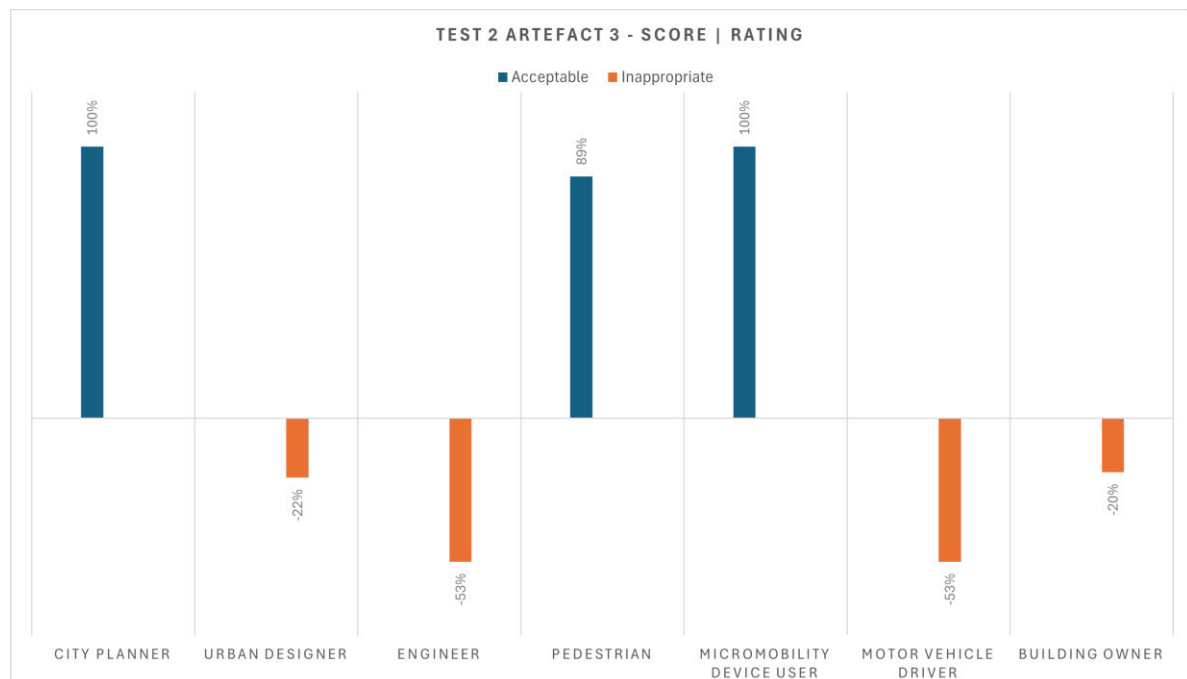
### The System Evaluation for the Test 2 Artefact 3 in Experiment 3:

The system evaluated the artefact's statistical data analysis against the requirements set out for individual stakeholders. The system produced an autogenerated result as shown in the evaluation table in Sub-Section 4.4.8 for Test 2 Artefact 3 Evaluation.

The table shows the result of the evaluation for Test 2 Artefact 3 which results in a great improvement on the performance of the artefact for micromobility device user stakeholder with an improved score from 30% Acceptable in Artefact 3 to 100% Acceptable in Test 2 Artefact 3.

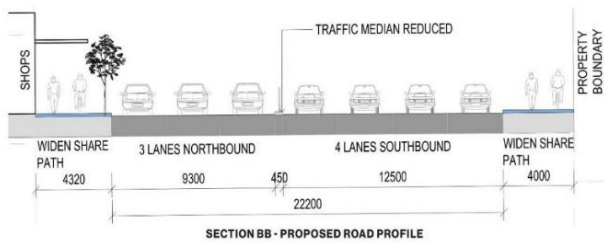
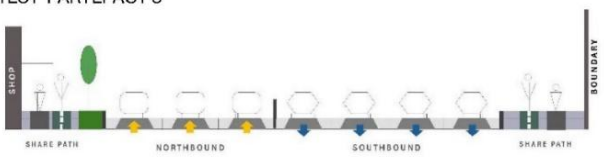

Based on the Available Data Value = 9.1, and the Visible Element Data = 2 of Test 2 Artefact 3, the summary of the Result is shown in the chart below for the artefact's score and rating for each stakeholder:

**Table 4.56: Test 2 Artefact 3 Evaluation Summary**



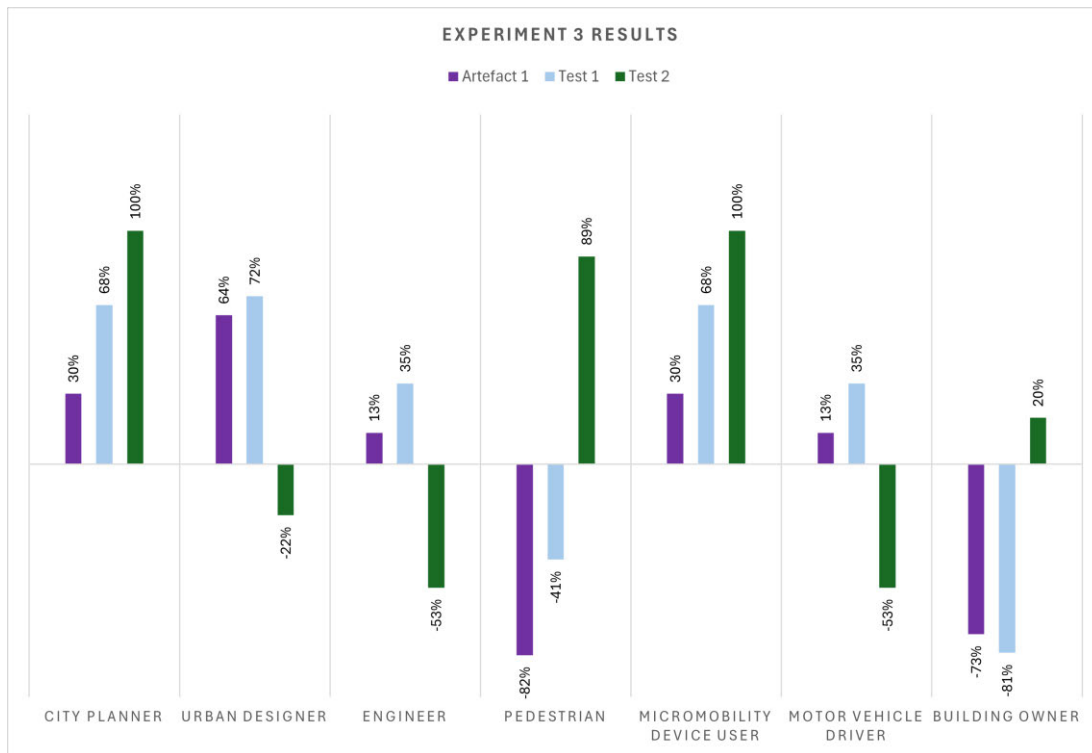
#### 4.4.7 PERFORMANCE RESULTS

This Sub-Section shows the results for Experiment 3. The results for artefact graphic comparison and the score and ranking for each for *urban designer* and for *micromobility device user* based on the parameters set out in Calibration Tables 1, 2 and 3 are shown below. As well the overall results summary for Experiment 3 is summarised in the chart below and the overall performance comparison are set out to illustrate the percentage data value and the percentage data failure for all three artefacts in Experiment 3.

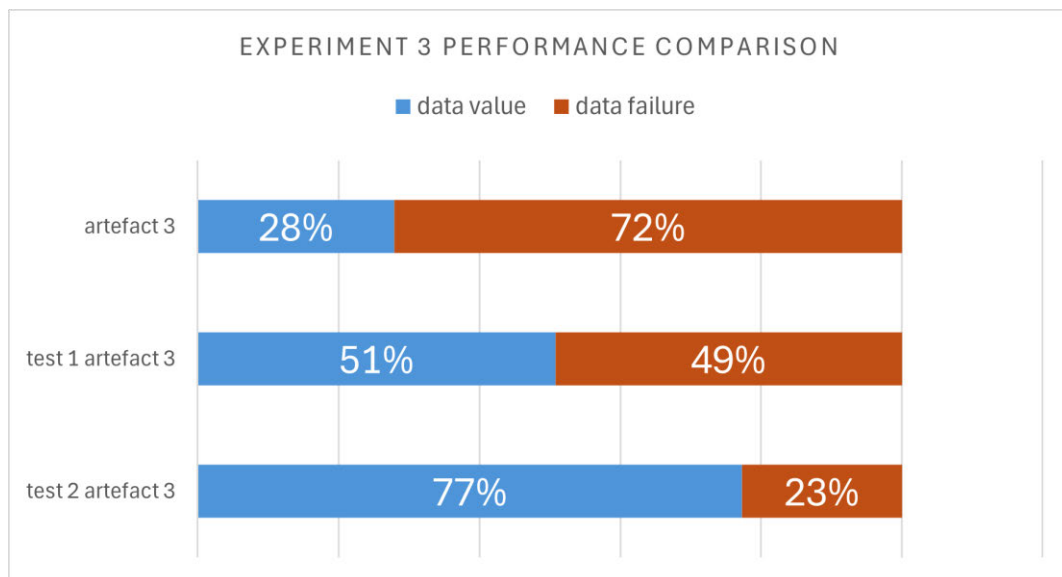
EXPERIMENT 3		urban designer	micromobility device user
<b>ARTEFACT 3</b> 		87% <b>Acceptable</b>	52% <b>Acceptable</b>
<b>TEST 1 ARTEFACT 3</b> 		90% <b>Acceptable</b>	84% <b>Acceptable</b>
<b>TEST 2 ARTEFACT 3</b> 		10% <b>Inappropriate</b>	100% <b>Acceptable</b>

**Figure 4.47:** Results Comparison for urban designer and micromobility device user.

**Table 4.57: Experiment 3 Results Summary**



**Table 4.58: Experiment 3 Artefacts Performance Results**



## 4.4.8 ANALYSIS & EVALUATION TABLES

### Artefact 3 Analysis & Evaluation

Table 4.59: Artefact 3 Analysis


	urban object	urban element	parameter	shape				label				weight				Sum	Artefact #3		
				point	line/curve	plane	solid	v0	v1	v2	v3	w0	w1	w2	w3				
				u0	u1	u2	u3	text/number/r/symbol	line/curve	plane	solid	point area	thickn/ess/colour	hatch/colour	hatch/colour				
0	road	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	motor vehicle	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	pedestrian	path	visibility	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0
			count	0	0	2	0	0	0	2	0	0	0	0	0	1	0	0	0
			amount	0	0	0.4	0	0	0	0.2	0	0	0	0	0.1	0	0	0	0.7
1	micromobility d	path	visibility	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0
			count	0	0	2	0	0	0	1	0	0	0	0	1	0	0	0	0
			amount	0	0	0.4	0	0	0	0.1	0	0	0	0	0.1	0	0	0	0.6
1	2																		1.3 PATH DATA VALUE
1	road	edge	visibility	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			count	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0.4
1	pedestrian	edge	visibility	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0
			count	0	4	0	0	0	0	2	0	0	0	0	2	0	0	0	0
			amount	0	0.8	0	0	0	0	0.2	0	0	0	0	0.2	0	0	0	1.2
1	micromobility d	edge	visibility	0	1	0	0	0	0	1	0	0	0	0	1	0	0	0	0
			count	0	4	0	0	0	0	2	0	0	0	0	2	0	0	0	0
			amount	0	0.8	0	0	0	0	0.2	0	0	0	0	0.2	0	0	0	1.2
1	3																		2.8 EDGE DATA VALUE
1	pedestrian	zone	visibility	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0
			count	0	0	2	0	0	0	4	0	0	0	0	1	0	0	0	0
			amount	0	0	0.4	0	0	0	0.4	0	0	0	0	0.1	0	0	0	0.9
1	motor vehicle	zone	visibility	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0
			count	0	0	7	0	0	0	9	0	0	0	0	1	0	0	0	0
			amount	0	0	1.4	0	0	0	0.9	0	0	0	0	0.1	0	0	0	2.4
1	micromobility d	zone	visibility	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0
			count	0	0	2	0	0	0	4	0	0	0	0	1	0	0	0	0
			amount	0	0	0.4	0	0	0	0.4	0	0	0	0	0.1	0	0	0	0.9
1	3																		4.2 ZONE DATA VALUE
0	micromobility d	node	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0																		0.0 NODE DATA VALUE
0	micromobility d	landmark	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0																		0.0 LANDMARK DATA VALUE
0	micromobility d	district	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0																		0.0 DISTRICT DATA VALUE
3	VISIBLE ELEMENT DATA																	8.3	AVAILABLE DATA VALUE
4	REQUIRED ANALYSED DATA																		

**Table 4.60: Artefact 3 Evaluation**

EVALUATION										
System calculates:										
urban object-urban element	urban element visibility	city planner	urban designer	engineer	pedestrian	micromobility device user	motor vehicle driver	building owner		
road-path	0	-1	-1	-1	-1	-1	-1	0		
motor vehicle-path	0	-1	-1	-1	-1	-1	-1	0		
pedestrian-path	1	0	0	0	0	0	0	-1		
micromobility device-path	1	0	0	0	0	0	0	-1		
DATA PENALTY		-2	-2	-2	-2	-2	-2	-2	-2	-2
PATH DATA VALUE LESS PENALTY		-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-1
ELEMENT PENALTY		0	0	0	0	0	0	-1		
road-edge	1	-1	0	0	-1	-1	0	-1		
pedestrian-edge	1	-1	0	0	-1	-1	0	-1		
micromobility device-edge	1	-1	0	0	-1	-1	0	-1		
DATA PENALTY		-3	0	0	-3	-3	0	-3		
EDGE DATA VALUE LESS PENALTY		-1	2.8	2.8	-1	-1	2.8	-1		
ELEMENT PENALTY		-1	0	0	-1	-1	0	-1		
pedestrian-zone	1	0	0	-1	0	0	-1	0		
motor vehicle-zone	1	0	0	-1	0	0	-1	0		
micromobility device-zone	1	0	0	-1	0	0	-1	0		
DATA PENALTY		0	0	-3	0	0	-3	0		
ZONE DATA VALUE LESS PENALTY		4.2	4.2	-1	4.2	4.2	-1	4.2		
ELEMENT PENALTY		0	0	-1	0	0	-1	0		
micromobility device-node	0	0	-1	0	-1	0	0	0		
DATA PENALTY		0	-1	0	-1	0	0	0		
NODE DATA VALUE LESS PENALTY		0	-1	0	-1	0	0	0		
ELEMENT PENALTY		0	-1	0	-1	0	0	0		
micromobility device-landmark	0	0	0	0	0	0	0	0		
DATA PENALTY		0	0	0	0	0	0	0		
LANDMARK DATA VALUE LESS PENALTY		0	0	0	0	0	0	0		
ELEMENT PENALTY		0	0	0	0	0	0	0		
micromobility device-district	0	0	0	0	0	0	0	0		
DATA PENALTY		0	0	0	0	0	0	0		
DISTRICT DATA VALUE LESS PENALTY		0	0	0	0	0	0	0		
ELEMENT PENALTY		0	0	0	0	0	0	0		
<b>SCORING</b>										
STAKEHOLDER DATA VALUE		2.5	5.3	1.1	1.5	2.5	1.1	2.2		
VALUABLE DATA		30%	64%	13%	18%	30%	13%	27%		
<b>RATING</b>										
REQUIRED ELEMENT DATA		2	4	2	3	2	2	1		
TOTAL ELEMENT PENALTY		-1	-1	-1	-2	-1	-1	-2		
ELEMENT DATA FAILURE		25%	25%	25%	50%	25%	25%	50%		
Rated As:		Acceptable	Acceptable	Acceptable	Inappropriate	Acceptable	Acceptable	Inappropriate		
<b>RESULT</b>		<b>30%</b>	<b>64%</b>	<b>13%</b>	<b>82%</b>	<b>30%</b>	<b>13%</b>	<b>73%</b>		
		<b>Acceptable</b>	<b>Acceptable</b>	<b>Acceptable</b>	<b>Inappropriate</b>	<b>Acceptable</b>	<b>Acceptable</b>	<b>Inappropriate</b>		

# Test 1 Artefact 3 Analysis & Evaluation

Table 4.61: Test 1-Artefact 3 Analysis



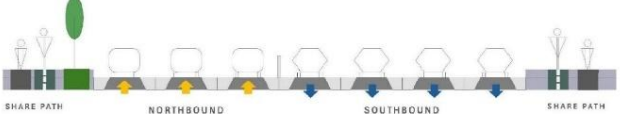
urban object	urban element	parameter	shape				label				weight				ANALYSIS Sum	drawing#3		
			point	line/curve	plane	solid	text/number/symbol	line/curve	plane	solid	point area	thickn ess/colour	hatch/colour	hatch/colour				
			u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3				
0	road	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
1	motor vehicle	path	visibility	0	0	1	0	0	0	1	0	0	0	1	0	0	0	2.4
			count	0	0	7	0	0	0	7	0	0	0	3	0	0	0	
			amount	0	0	1.4	0	0	0	0.7	0	0	0	0.3	0	0	0	
1	pedestrian	path	visibility	0	0	1	0	0	0	1	0	0	0	1	0	0	0	1.1
			count	0	0	4	0	0	0	2	0	0	0	1	0	0	0	
			amount	0	0	0.8	0	0	0	0.2	0	0	0	0.1	0	0	0	
1	micromobility device	path	visibility	0	1	1	0	0	0	1	0	0	0	1	0	0	0	1.8
			count	0	2	4	0	0	0	4	0	0	0	2	0	0	0	
			amount	0	0.4	0.8	0	0	0	0.4	0	0	0	0.2	0	0	0	5.3 PATH DATA VALUE
1	road	edge	visibility	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0.7
			count	0	3	0	0	0	0	0	0	0	1	0	0	0	0	
			amount	0	0.6	0	0	0	0	0	0	0	0.1	0	0	0	0	
1	pedestrian	edge	visibility	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0.7
			count	0	0	2	0	0	0	2	0	0	0	1	0	0	0	
			amount	0	0	0.4	0	0	0	0.2	0	0	0	0.1	0	0	0	
0	micromobility device	edge	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.4 EDGE DATA VALUE
1	pedestrian	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	0	0	2.4
			count	0	0	7	0	0	0	9	0	0	0	1	0	0	0	
			amount	0	0	1.4	0	0	0	0.9	0	0	0	0.1	0	0	0	
1	motor vehicle	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0.7
			count	0	0	2	0	0	0	2	0	0	0	1	0	0	0	
			amount	0	0	0.4	0	0	0	0.2	0	0	0	0.1	0	0	0	
1	micromobility device	zone	visibility	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0.9
			count	0	0	2	0	0	0	4	0	0	0	1	0	0	0	
			amount	0	0	0.4	0	0	0	0.4	0	0	0	0.1	0	0	0	4.0 ZONE DATA VALUE
0	micromobility device	node	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0 NODE DATA VALUE
0	micromobility device	landmark	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0 LANDMARK DATA VALUE
0	micromobility device	district	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
			count	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0 DISTRICT DATA VALUE
3	VISIBLE ELEMENT DATA															10.7	AVAILABLE DATA VALUE	
4	REQUIRED ANALYSED DATA																	

**Table 4.62: Test 1-Artifact 3 Evaluation**

EVALUATION												
System calculates:												
urban object-urban element	urban element visibility	city planner	urban designer	engineer	pedestrian	micromobility device user	motor vehicle driver	building owner				
road-path	0	-1	-1	-1	-1	-1	-1	0				
motor vehicle-path	1	0	0	0	0	0	0	-1				
pedestrian-path	1	0	0	0	0	0	0	-1				
micromobility device-path	1	0	0	0	0	0	0	-1				
DATA PENALTY		-1	-1	-1	-1	-1	-1	-1	-3			
PATH DATA VALUE LESS PENALTY		4.3	4.3	4.3	4.3	4.3	4.3	4.3	-1			
ELEMENT PENALTY		0	0	0	0	0	0	0	-1			
road-edge	1	-1	0	0	-1	-1	0	-1				
pedestrian-edge	1	-1	0	0	-1	-1	0	-1				
micromobility device-edge	0	0	-1	-1	0	0	-1	0				
DATA PENALTY		-2	-1	-1	-2	-2	-1	-2	-2			
EDGE DATA VALUE LESS PENALTY		-1	0.4	0.4	-1	-1	0.4	0.4	-1			
ELEMENT PENALTY		-1	0	0	-1	-1	0	-1	-1			
pedestrian-zone	1	0	0	-1	0	0	-1	0				
motor vehicle-zone	1	0	0	-1	0	0	-1	0				
micromobility device-zone	1	0	0	-1	0	0	-1	0				
DATA PENALTY		0	0	-3	0	0	-3	0	0			
ZONE DATA VALUE LESS PENALTY		4.0	4.0	-1	4.0	4.0	-1	-1	4.0			
ELEMENT PENALTY		0	0	-1	0	0	-1	0	0			
micromobility device-node	0	0	-1	0	-1	0	0	0				
DATA PENALTY		0	-1	0	-1	0	0	0	0			
NODE DATA VALUE LESS PENALTY		0	-1	0	-1	0	0	0	0			
ELEMENT PENALTY		0	-1	0	-1	0	0	0	0			
micromobility device-landmark	0	0	0	0	0	0	0	0				
DATA PENALTY		0	0	0	0	0	0	0	0			
LANDMARK DATA VALUE LESS PENALTY		0	0	0	0	0	0	0	0			
ELEMENT PENALTY		0	0	0	0	0	0	0	0			
micromobility device-district	0	0	0	0	0	0	0	0				
DATA PENALTY		0	0	0	0	0	0	0	0			
DISTRICT DATA VALUE LESS PENALTY		0	0	0	0	0	0	0	0			
ELEMENT PENALTY		0	0	0	0	0	0	0	0			
<b>SCORING</b>												
<b>STAKEHOLDER DATA VALUE VALUABLE DATA</b>		7.3 68%	7.7 72%	3.7 35%	6.3 59%	7.3 68%	3.7 35%	2 19%				
<b>RATING</b>												
<b>REQUIRED ELEMENT DATA</b>		2	4	2	3	2	2	1				
<b>TOTAL ELEMENT PENALTY</b>		-1	-1	-1	-2	-1	-1	-2				
<b>ELEMENT DATA FAILURE</b>		25%	25%	25%	50%	25%	25%	50%				
<b>Rated As:</b>		Acceptable	Acceptable	Acceptable	Inappropriate	Acceptable	Acceptable	Inappropriate				
<b>RESULT</b>		68% Acceptable	72% Acceptable	35% Acceptable	41% Inappropriate	68% Acceptable	35% Acceptable	81% Inappropriate				

# Test 2 Artefact 3 Analysis & Evaluation

Table 4.63: Test 2-Artefact 3 Analysis



		shape				label				weight				ANALYSIS artefact #3
		u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3	Sum
urban object	urban element	parameter	point	line/curve	plane	solid	text/number/symbol	line/curve	plane	solid	point area	thickn ess/colour	hatch/colour	hatch/colour
1	road	path	visibility	1	0	0	0	1	0	0	0	0	0	0
		count	2	0	0	0	2	0	0	0	0	0	0	0
		amount	0.2	0	0	0	0.1	0	0	0	0	0	0	0.3
1	motor vehicle	path	visibility	0	1	0	0	1	0	0	0	0	0	0
		count	0	6	0	0	2	0	0	0	0	0	0	0
		amount	0	4.8	0	0	0.1	0	0	0	0	0	0	4.9
1	pedestrian	path	visibility	1	0	1	0	1	0	0	0	1	0	0
		count	2	0	1	0	1	0	0	0	1	0	0	0
		amount	0.2	0	0.2	0	0.05	0	0	0	0.05	0	0	0.5
1	micromobility device	path	visibility	1	0	1	0	1	0	0	0	1	0	1
		count	2	0	1	0	1	0	0	0	1	0	1	0
		amount	0.2	0	0.2	0	0.05	0	0	0	0.05	0	0.1	0
1	4													6.3 PATH DATA VALUE
0	road	edge	visibility	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0
		amount	0	0	0	0	0	0	0	0	0	0	0	0.0
0	pedestrian	edge	visibility	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0
		amount	0	0	0	0	0	0	0	0	0	0	0	0.0
0	micromobility device	edge	visibility	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0
		amount	0	0	0	0	0	0	0	0	0	0	0	0.0
0	0													0 EDGE DATA VALUE
1	pedestrian	zone	visibility	1	0	1	0	1	0	0	0	0	0	1
		count	2	0	2	0	1	0	0	0	0	0	1	0
		amount	0.2	0	0.4	0	0.05	0	0	0	0	0	0.1	0
1	motor vehicle	zone	visibility	1	0	1	0	1	0	0	0	0	0	1
		count	7	0	1	0	2	0	0	0	0	0	1	0
		amount	0.7	0	0.2	0	0.1	0	0	0	0	0	0.1	0
1	micromobility device	zone	visibility	1	0	1	0	1	0	1	0	0	0	1
		count	2	0	2	0	1	0	2	0	0	0	1	0
		amount	0.2	0	0.4	0	0.05	0	0.2	0	0	0	0.1	0
1	3													2.8 ZONE DATA VALUE
0	micromobility device	node	visibility	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0
		amount	0	0	0	0	0	0	0	0	0	0	0	0.0
0	0													0 NODE DATA VALUE
0	micromobility device	landmark	visibility	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0
		amount	0	0	0	0	0	0	0	0	0	0	0	0.0
0	0													0 LANDMARK DATA VALUE
0	micromobility device	district	visibility	0	0	0	0	0	0	0	0	0	0	0
		count	0	0	0	0	0	0	0	0	0	0	0	0
		amount	0	0	0	0	0	0	0	0	0	0	0	0.0
0	0													0 DISTRICT DATA VALUE
2	VISIBLE ELEMENT DATA													9.1 AVAILABLE DATA VALUE
4	REQUIRED ANALYSED DATA													

**Table 4.64: Test 2-Artifact 3 Evaluation**

EVALUATION									
System calculates:									
urban object-urban element	urban element visibility	city planner	urban designer	engineer	pedestrian	micromobility device user	motor vehicle driver	building owner	
road-path	1	0	0	0	0	0	0	-1	
motor vehicle-path	1	0	0	0	0	0	0	-1	
pedestrian-path	1	0	0	0	0	0	0	-1	
micromobility device-path	1	0	0	0	0	0	0	-1	
	DATA PENALTY	0	0	0	0	0	0	-4	
	PATH DATA VALUE LESS PENALTY	6.3	6.3	6.3	6.3	6.3	6.3	-1	
	ELEMENT PENALTY	0	0	0	0	0	0	-1	
road-edge	0	0	-1	-1	0	0	-1	0	
pedestrian-edge	0	0	-1	-1	0	0	-1	0	
micromobility device-edge	0	0	-1	-1	0	0	-1	0	
	DATA PENALTY	0	-3	-3	0	0	-3	0	
	EDGE DATA VALUE LESS PENALTY	0	-1	-1	0	0	-1	0	
	ELEMENT PENALTY	0	-1	-1	0	0	-1	0	
pedestrian-zone	1	0	0	-1	0	0	-1	0	
motor vehicle-zone	1	0	0	-1	0	0	-1	0	
micromobility device-zone	1	0	0	-1	0	0	-1	0	
	DATA PENALTY	0	0	-3	0	0	-3	0	
	ZONE DATA VALUE LESS PENALTY	2.8	2.8	-1	2.8	2.8	-1	2.8	
	ELEMENT PENALTY	0	0	-1	0	0	-1	0	
micromobility device-node	0	0	-1	0	-1	0	0	0	
	DATA PENALTY	0	-1	0	-1	0	0	0	
	NODE DATA VALUE LESS PENALTY	0	-1	0	-1	0	0	0	
	ELEMENT PENALTY	0	-1	0	-1	0	0	0	
micromobility device-landmark	0	0	0	0	0	0	0	0	
	DATA PENALTY	0	0	0	0	0	0	0	
	LANDMARK DATA VALUE LESS PENALTY	0	0	0	0	0	0	0	
	ELEMENT PENALTY	0	0	0	0	0	0	0	
micromobility device-district	0	0	0	0	0	0	0	0	
	DATA PENALTY	0	0	0	0	0	0	0	
	DISTRICT DATA VALUE LESS PENALTY	0	0	0	0	0	0	0	
	ELEMENT PENALTY	0	0	0	0	0	0	0	
<b>SCORING</b>									
<b>STAKEHOLDER DATA VALUE</b>		9.1	7.1	4.3	8.1	9.1	4.3	1.8	
<b>VALUABLE DATA</b>		100%	78%	47%	89%	100%	47%	20%	
<b>RATING</b>									
<b>REQUIRED ELEMENT DATA</b>		2	4	2	3	2	2	1	
<b>TOTAL ELEMENT PENALTY</b>		0	-2	-2	-1	0	-2	-1	
<b>ELEMENT DATA FAILURE</b>		0%	50%	50%	25%	0%	50%	25%	
<b>Rated As:</b>		Acceptable	Inappropriate	Inappropriate	Acceptable	Acceptable	Inappropriate	Acceptable	
<b>RESULT</b>		100%	22%	53%	89%	100%	53%	20%	
		Acceptable	Inappropriate	Inappropriate	Acceptable	Acceptable	Inappropriate	Acceptable	

## 4.5 EXPERIMENT 4

Experiment 4 is an evaluation of three artefacts. The first is Artefact 4. The second is Test 1 Artefact 4 and the third is Test 2 Artefact 4. At the conclusion of the experiment, a comparison of the three results will be presented.

### 4.5.1 BACKGROUND ARTEFACT 4

Project 4 relates to a cycleway network in the Central River City, a city region as part of the vision developed by the Greater Cities Commission<sup>1</sup>. The vision of the NSW Government is to provide a safe and connected cycleway across Greater Sydney. To enable this, the Strategic Cycleway Corridor program was developed to establish cross-city connections that connect centres, precincts and places, and to allow councils to progressively expand local networks.

The first instalment of the Strategic Cycleway Corridor was for the Eastern Harbour City network adopted in April 2022. Project 4 relates to the second instalment, which is an expansion of the cycleway network for Central River City.



**Figure 4.48:** City District Plan. Source: Greater Sydney Commission (2018).

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<sup>1</sup> The Greater Cities Commission was dissolved on 1 January 2024, and all NSW strategic planning functions and responsibilities have been transferred to the new Department of Planning Housing and Infrastructure.

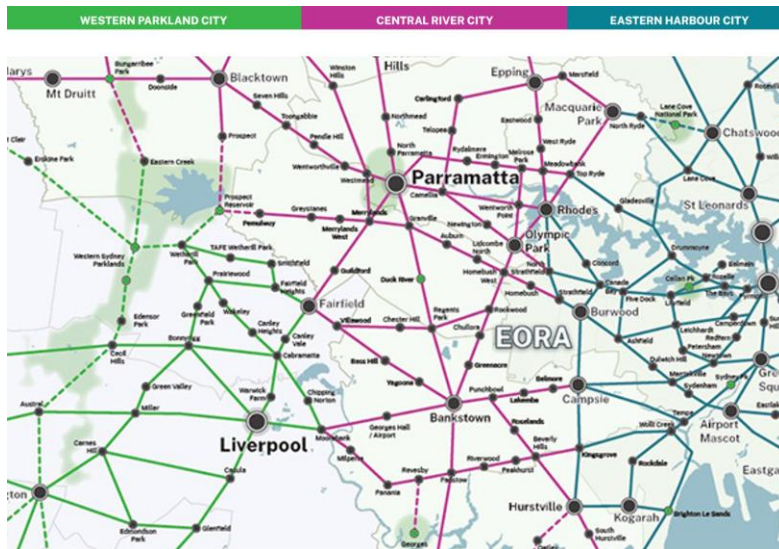
The city is currently home to more than two million people and is expected to grow to 2.4 million by 2036. Short daily car trips are unsustainable. 2 million daily car trips in Greater Sydney are less than 2 kilometres and 6 million daily are less than 5 kilometres. As well, congestion is economically not viable in the long run. Hence the commission has identified opportunities that can be established by delivering a cycleway network corridor.

The proposed cycleway corridor will span throughout the Central River City region and will connect to the Eastern Harbour City network. Hence, the development of the corridor is contingent on ongoing collaboration between Transport for NSW, local councils, bike groups and other key stakeholders.

Consequently, three rounds of engagement were undertaken. Round 1 was identifying local priorities and network validation. Round 2 was confirming corridors, and Round 3 for corridor staging. Round 2 and Round 3 is an iterative process for review and refining corridors. Project 4 of this research relates to the communication artefacts used during Round 1 engagement.

#### PROPOSED DRAFT CORRIDOR

The proposed Central River City Strategic Cycleway Corridor is illustrated below. It identifies at a high-level key connection between centres based on a strategic vision for Greater Sydney. The details as to how this can be accomplished on the ground plane and on site is to be developed as the project progresses.

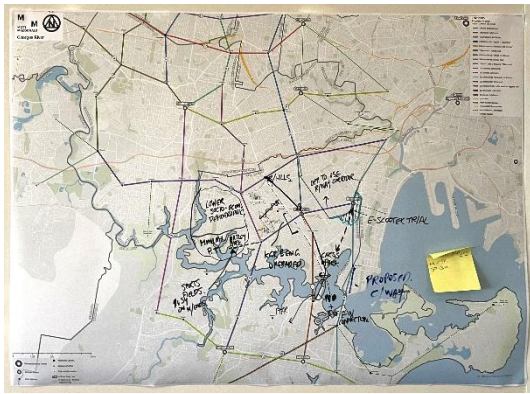


**Figure 4.49:** Strategic Cycleway Corridors. Source: TfNSW.

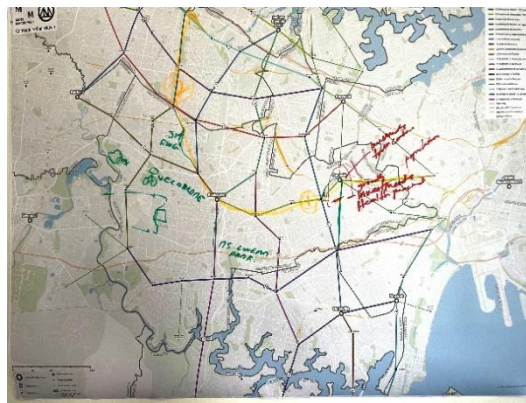
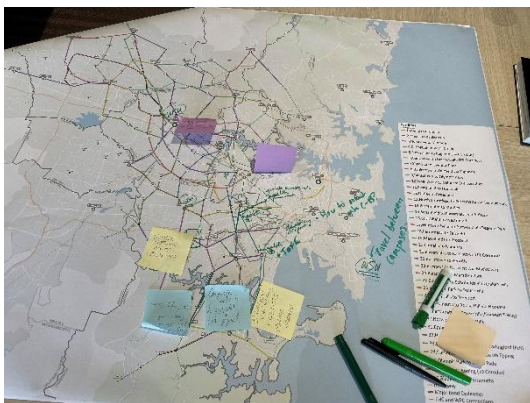
The network is ambitious and is at a macro-level. It is large and covers the sprawling greater Sydney. Map of the route with maximum coverage will form the backbone and its aim is for connecting the greater city. This will result in hundreds of kilometres of cycleway that will be delivered within greater Sydney moving forward.

## THE PROCESS

The urban design activities involved during the design process was extensive. Workshops with stakeholders were carried out and were crucial at providing details relating to strategic local connections and identifying priorities that need to be considered. Exploring how key connections relate and align with local communities' and local government objectives also featured. Communication artefacts used were varied but were mainly depicting large areas like maps. Network design development was dynamic and from a broader view. Lines, markings and symbols were used, and various colours to add meaning to lines. Samples of artefacts used as shown below:



**Rate:**  
**Level of Detail:**  
 1  
**Level of Abstraction:**  
 1



**Figure 4.50:** Communication artefact samples used.

ARTEFACT 4

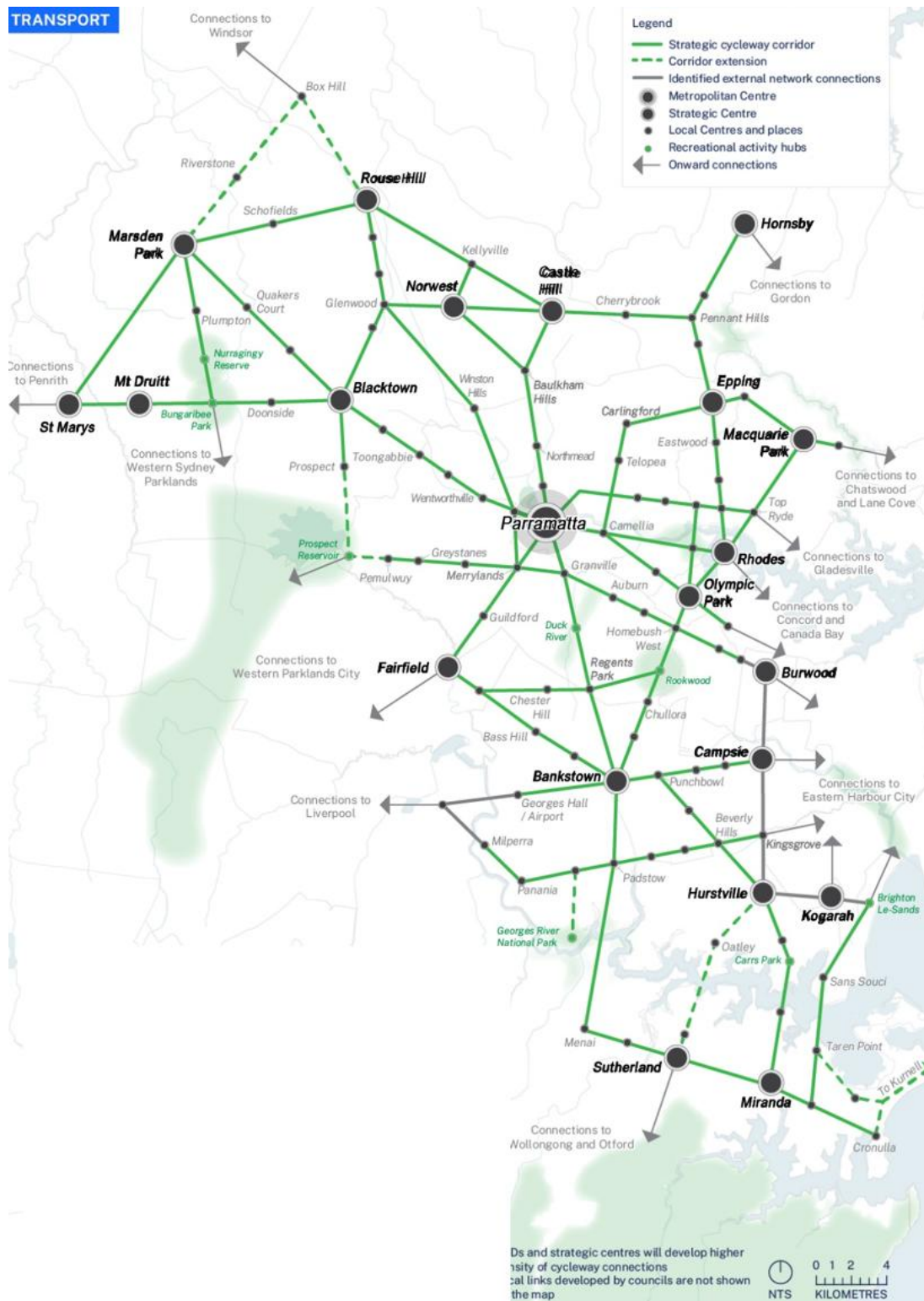


Figure 4.51: Strategic cycleway corridor map for Central River City. Source: TfNSW (2023).

Artefact 4 is a sample of a communication artefact used in this urban design project. This will be analysed and evaluated for Experiment 4. This artefact was chosen as it is different to Artefacts 1, 2 and 3 which feature smaller focused urban areas. Artefact 4 feature a large geographic area and is in plan view of the proposed corridor design.

#### 4.5.2 ARTEFACT 4 – LAYERS ANALYSIS

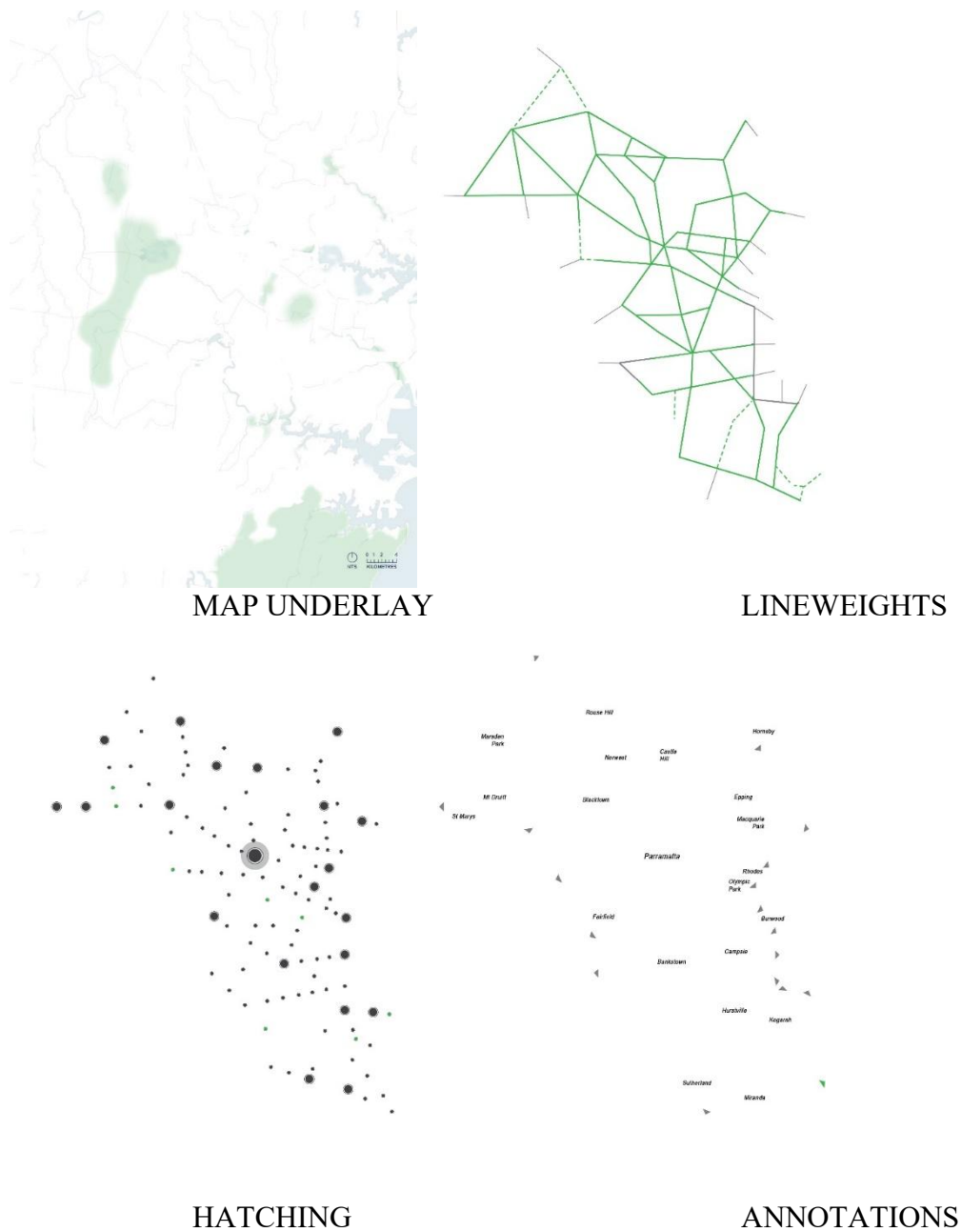


Figure 4.52: Artefact 4 Layers Analysis.

GRAPHIC ALGEBRA:

UNDERLAY ANALYSIS | GRAPHIC ALGEBRA:

SHAPE = PLANE; ALGEBRA =  $U_2 W_2$

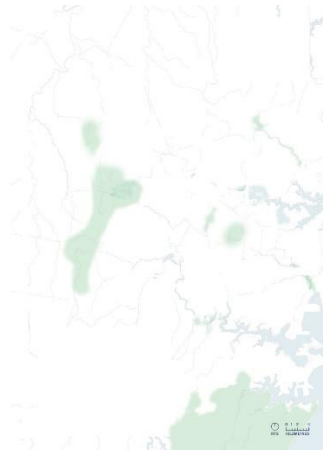


Figure 4.53: Artefact 4 Map Underlay.

LINEWEIGHTS ANALYSIS | GRAPHIC WEIGHTS:

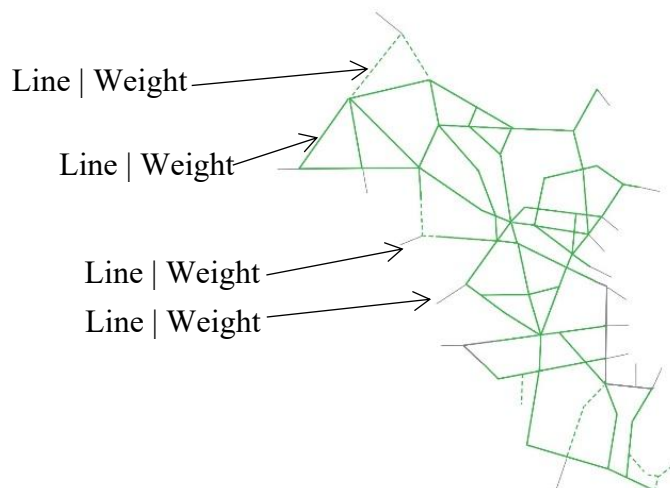






Figure 4.54: Artefact 4 Line Analysis.

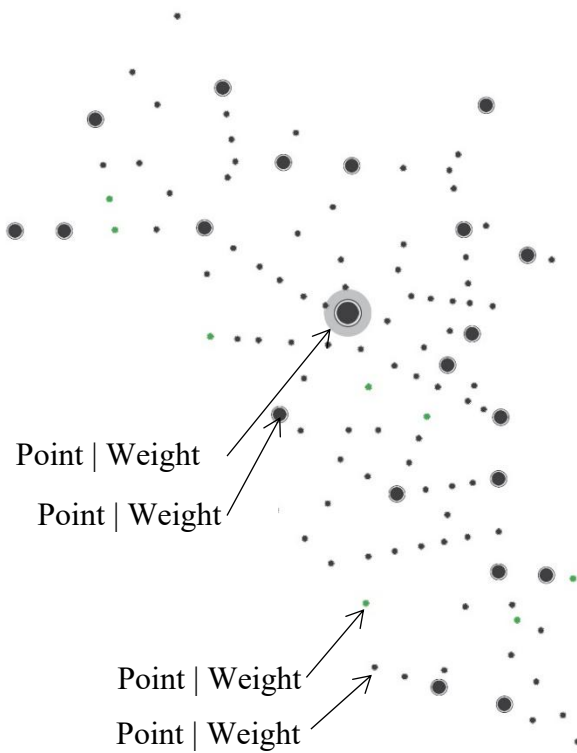
# GRAPHIC WEIGHTS ALGEBRA

**Table 4.65: Artefact 4 Line Weight Analysis**

	SHAPE: LINE   WEIGHTS	ALGEBRA
1		$U_{11} W_1$
2		$U_{11} W_1$
3		$U_{11} W_1$
4		$U_{11} W_1$





HATCHING ANALYSIS | GRAPHIC WEIGHTS:

HATCHING | WEIGHTS



**Figure 4.55: Artefact 4 Point and Weight Analysis.**

## GRAPHIC WEIGHTS ALGEBRA

	SHAPE: POINT   WEIGHTS	ALGEBRA
1		$U_0 W_2$
2		$U_0 W_2$
3		$U_0 W_2$
4		$U_0 W_2$

ANNOTATION ANALYSIS | GRAPHIC LABELS:

ANNOTATION | LABELS

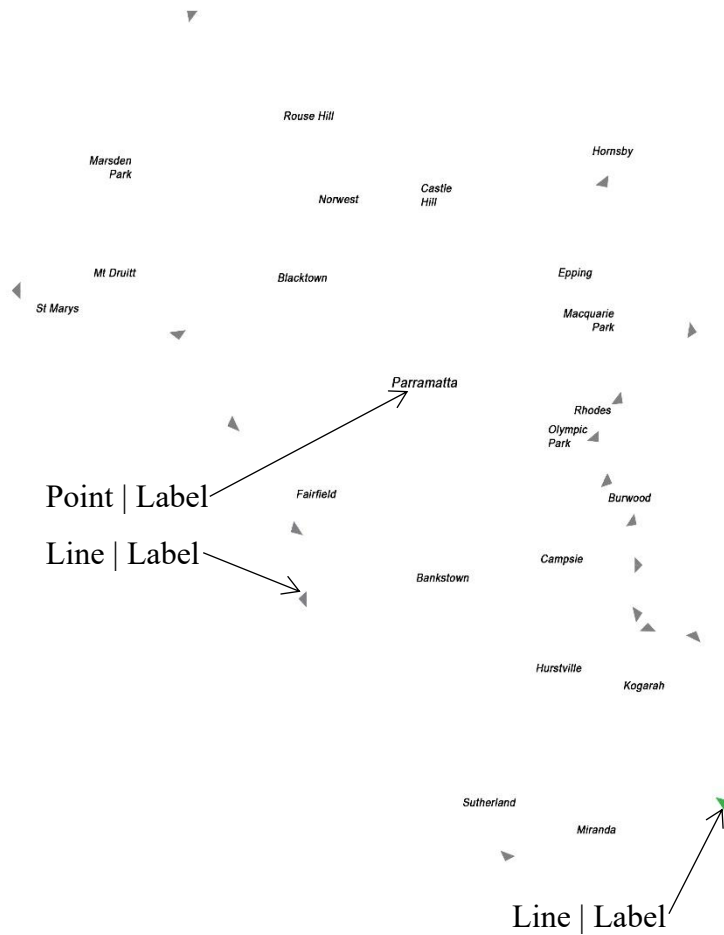




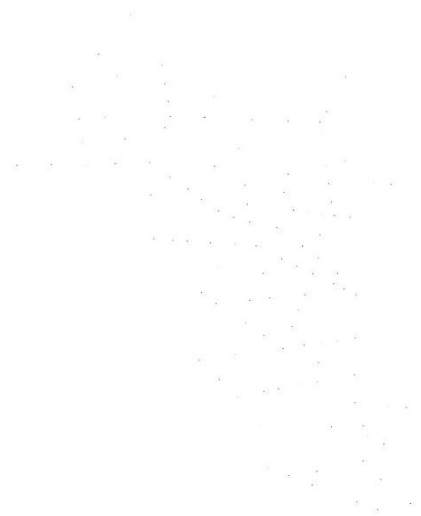
Figure 4.56: Artefact 4 Label Analysis.

GRAPHIC LABELS ALGEBRA

1	LABEL SET 1	ALGEBRA
		$U_0 V_1$
		$U_0 V_1$
2	LABEL SET 2	
	<i>Parramatta</i>	$U_{11} V_0$
	<i>Marsden Park</i>	$U_{11} V_0$
	<i>Mt Druitt</i>	$U_{11} V_0$
	<i>St Marys</i>	$U_{11} V_0$
	<i>Blacktown</i>	$U_{11} V_0$
	<i>Norwest</i>	$U_{11} V_0$
	<i>Castle Hill</i>	$U_{11} V_0$
	<i>Hornsby</i>	$U_{11} V_0$
	<i>Epping</i>	$U_{11} V_0$
	<i>Macquarie Park</i>	$U_{11} V_0$

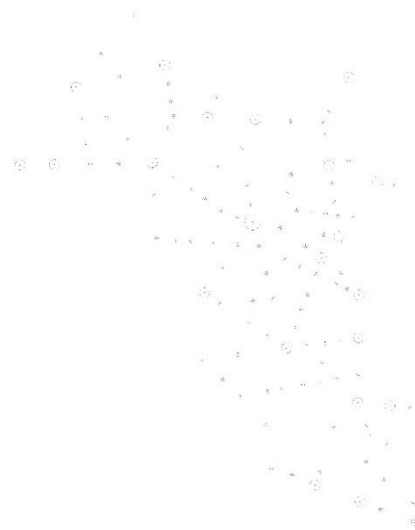
	<b><i>Rhodes</i></b>	$U_{11} V_0$
	<b><i>Olympic Park</i></b>	$U_{11} V_0$
	<b><i>Burwood</i></b>	$U_{11} V_0$
	<b><i>Fairfield</i></b>	$U_{11} V_0$
	<b><i>Bankstown</i></b>	$U_{11} V_0$
	<b><i>Campsie</i></b>	$U_{11} V_0$
	<b><i>Hurstville</i></b>	$U_{11} V_0$
	<b><i>Kogarah</i></b>	$U_{11} V_0$
	<b><i>Sutherland</i></b>	$U_{11} V_0$
	<b><i>Miranda</i></b>	$U_{11} V_0$
	<b><i>Rouse Hill</i></b>	$U_{11} V_0$

### 4.5.3 ARTEFACT 4 – STATISTICAL ANALYSIS



**Spatial points**

U0 2 (points in 2D space)



**Geographic location**

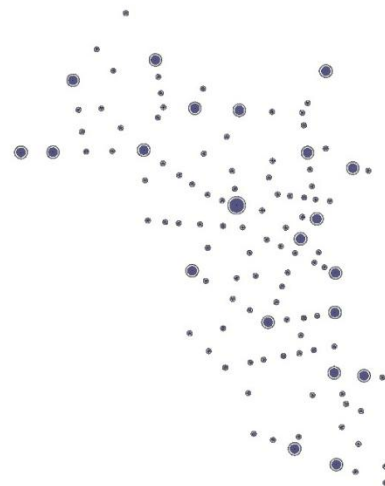
U0 2 (points in 2D space)



**Cities and towns**

U0 2 (points in 2D space)

W2 0 (centre area)

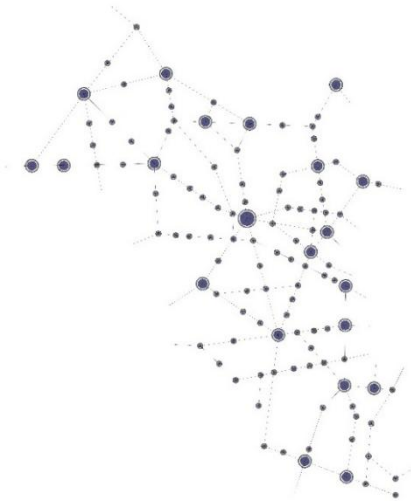


**Urban centres**

U0 2 (points in 2D space)

W2 0 (centre area)

W1 0 (local town boundary)



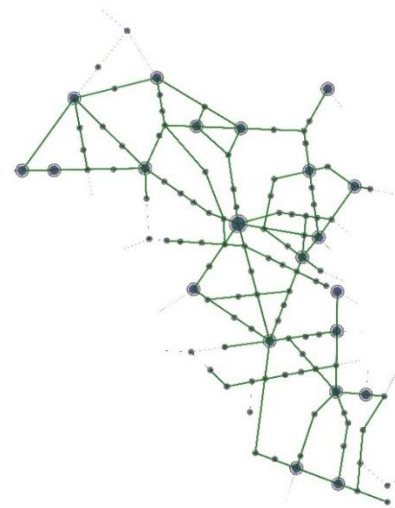
**Network cycle link**

U0 2 (points in 2D space)

U1 2 (line in 2D space)

W2 0 (blue)

W1 0 (dark grey)



**Strategic weighted corridor**

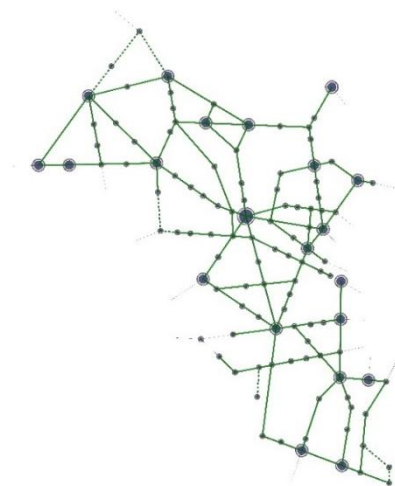
U0 2 (points in 2D space)

U1 2 (line in 2D space)

W2 0 (blue)

W1 0 (dark grey)

W2 1 (green)

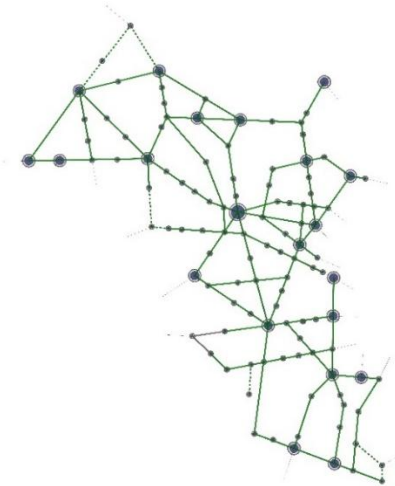


**Weighted corridor extension**

U0 2 (points in 2D space)

U1 2 (line in 2D space)

W2 0 (blue)



**Weighted external corridor extension**

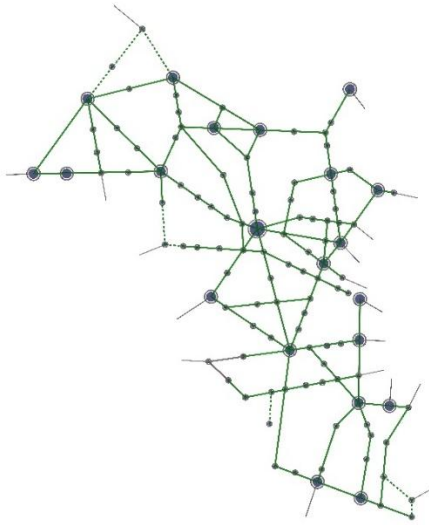
U0 2 (points in 2D space)

U1 2 (line in 2D space)

W2 0 (blue)

W1 0 (dark grey)

W2 2 (green, dash line type)



**Weighted onward connection**

U0 2 (points in 2D space)

U1 2 (line in 2D space)

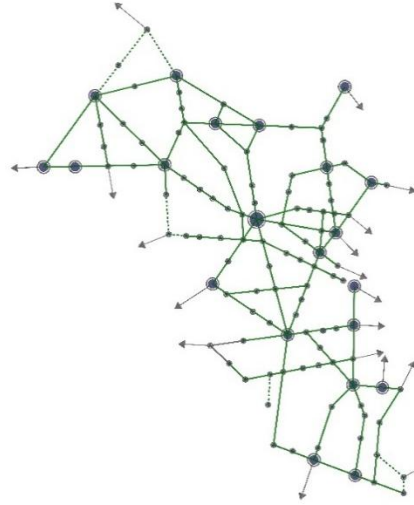
W2 0 (blue)

W1 0 (dark grey)

W2 2 (green, dash line type, brown)

W1 0 (dark grey)

W2 2 (green, dash line type, brown)



**Onward corridor direction**

U0 2 (points in 2D space)

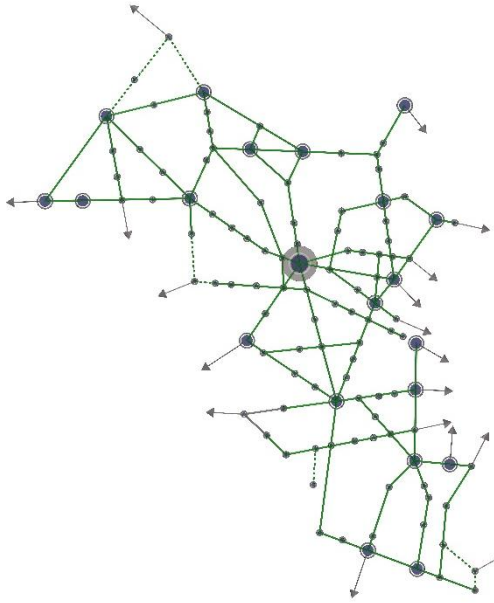
U1 2 (line in 2D space)

V0 1 (arrow)

W2 0 (blue)

W1 0 (dark grey)

W2 2 (green, dash line type, brown)



**Strategic Centre**

U0 2 (points in 2D space)

U1 2 (line in 2D space)

V0 1 (arrow)

W2 0 (blue, dark grey)

W1 0 (dark grey)

W2 2 (green, dash line type, brown)

**Figure 4.57:** Artefact 4 geometric transformation analysis.

#### 4.5.4 ARTEFACT 4 - ARTEFACT ANALYSIS & EVALUATION

The system will calibrate the system for the analysis using Calibration tables 1 and 2 below. This will test the system for communication of design for larger areas. The same assumptions as well will be adopted. Hence, path will need to be communicated through ways such as a line or plane and direction labels or weights to signify a channel for travelling along.

Calibration table 1 for experiment 4 will include landmark and district as these urban elements can be considered for larger scale areas. Edge however is turned off to minimise system bias as edge cannot easily be featured in geographic plan views.

**Table 4.66: Artefact 4 Calibration Table 1**

CALIBRATION 1		data type: [boolean (0 or 1)]							REQUIRED ELEMENT DATA
urban stakeholder	path	edge	zone	node	landmark	district	$\beta$		
city planner	1	0	1	0	0	1	0	3	
urban designer	1	0	1	1	1	0	0	4	
engineer	1	0	0	0	0	0	0	1	
pedestrian	1	0	1	1	1	0	0	4	
micromobility device user	1	0	1	0	1	0	0	3	
motor vehicle driver	1	0	0	0	0	1	0	2	
building owner	0	0	1	0	1	0	0	2	
$\sigma$	0	0	0	0	0	0	0	0	

Calibration table 2 also deals with identifying urban elements and urban objects. This will be adjusted to reflect the urban elements in Calibration table 1. As such, edge also is turned off, and both landmark and district will be turned on.

**Table 4.67: Artefact 4 Calibration Table 1**

CALIBRATION 2		data type: [boolean (0 or 1)]						
urban object	urban element							
	path	edge	zone	node	landmark	district	$\beta$	
road	1	0	0	0	0	0	0	
footpath	1	0	1	0	0	0	0	
building	0	0	0	0	0	0	0	
street furniture	0	0	0	0	0	0	0	
vegetation	0	0	0	0	0	0	0	
pedestrian	1	0	1	0	0	0	0	
micromobility device	1	0	1	1	1	1	0	
motor vehicle	1	0	1	0	0	0	0	
o	0	0	0	0	0	0	0	

**Table 4.68: Artefact 4 geometry count**

	Shape	Label	Weight
<i>Path-road</i>	0	0	0
<i>Path-motor vehicle</i>	0	0	0
<i>Path-pedestrian</i>	0	0	0
<i>Path-micro device</i>	U1=35	V1=17	W1=5
<i>Zone-pedestrian</i>	0	0	0
<i>Zone-motor vehicle</i>	0	0	0
<i>Zone-micro device</i>	0	0	0
<i>Node-micro device</i>	U0=20	V0=20	W0=2
<i>Landmark-micro</i>	U0=1	V0=1	W0=2
<i>District-micro</i>	U2=1	V2=1	W2=3

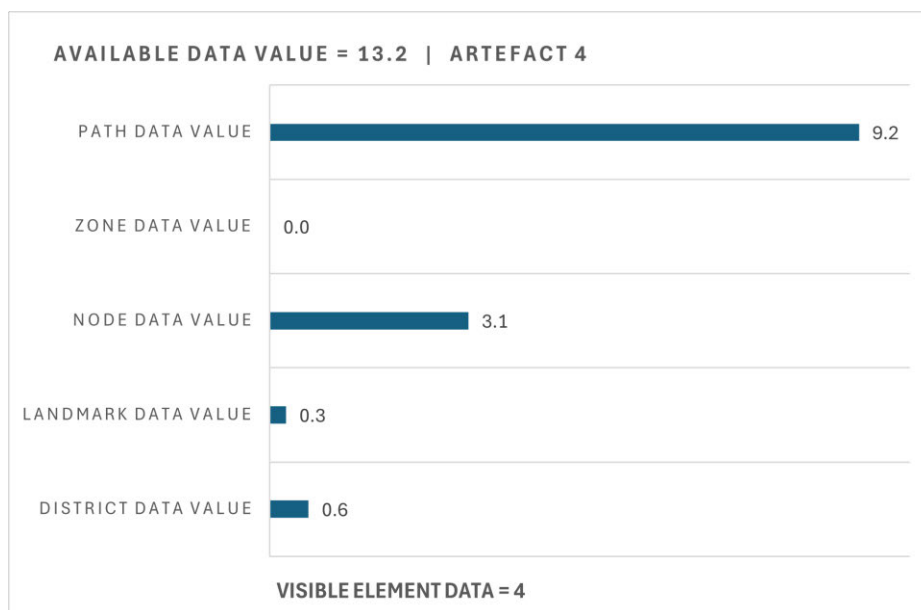
**ARTEFACT 3 SYSTEM ANALYSIS:**

Based on the graphical layers analysis, the system calculated the graphical statistics and calculated the values based on the adjusted Calibration tables 1 and 2, whilst using the same computation values set out in Calibration table 3.

The Available Data Value is 13.2 which is the total value of the artefact based on the visible urban elements combined and shown in the geometry count table. The system also calculated the number of urban elements in the artefact. Artefact 4 has a total of 4 elements, path, node, landmark and district (Visible Element Data). Note that no zone is featured. The

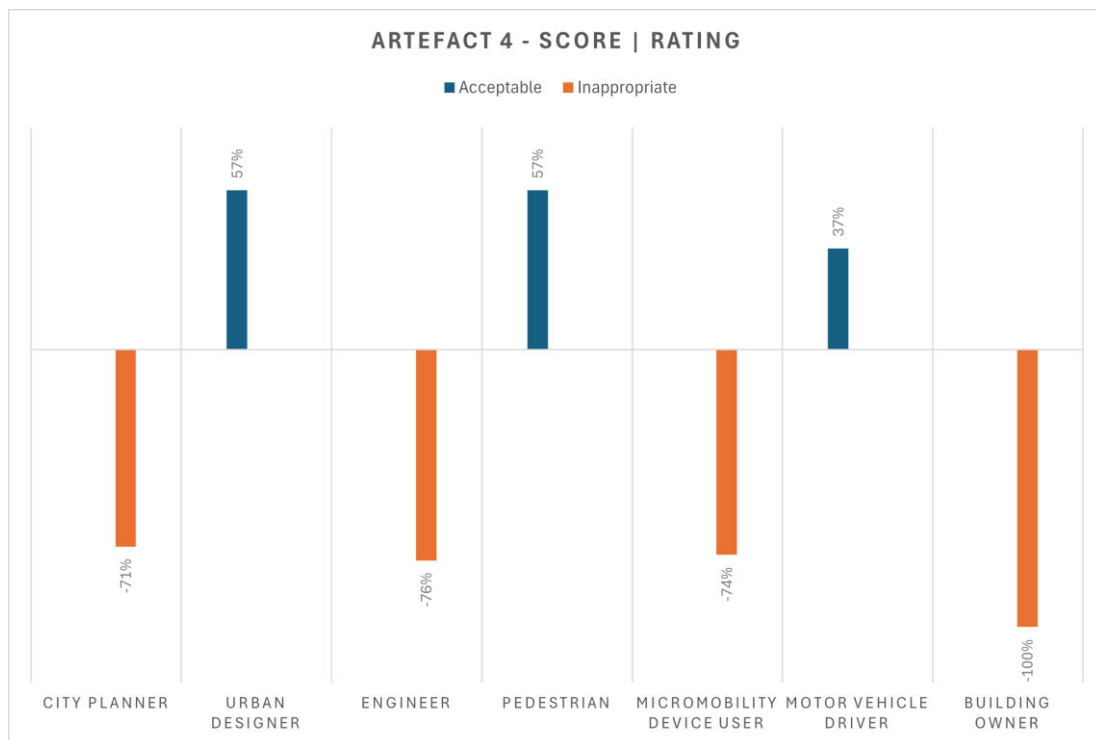
map underlay can also be read to communicate zones. However, the analysis did not consider that visible urban objects have been able to communicate this urban element. The analysis for Artefact 4 in Experiment 4 is shown in the table in Sub-Section 4.5.8 and the summary breakdown of the analysis data values are shown below:

**Table 4.69: Artefact 4 analysis summary**



As can be seen in the chart above, zone data is zero. As well the urban element edge has been turned off to avoid bias and urban elements of landmark and district are featured. These data values are automated inputs to the evaluation phase 2 of the system for Artefact 4.

**Table 4.70: Artefact 4 Evaluation Summary**

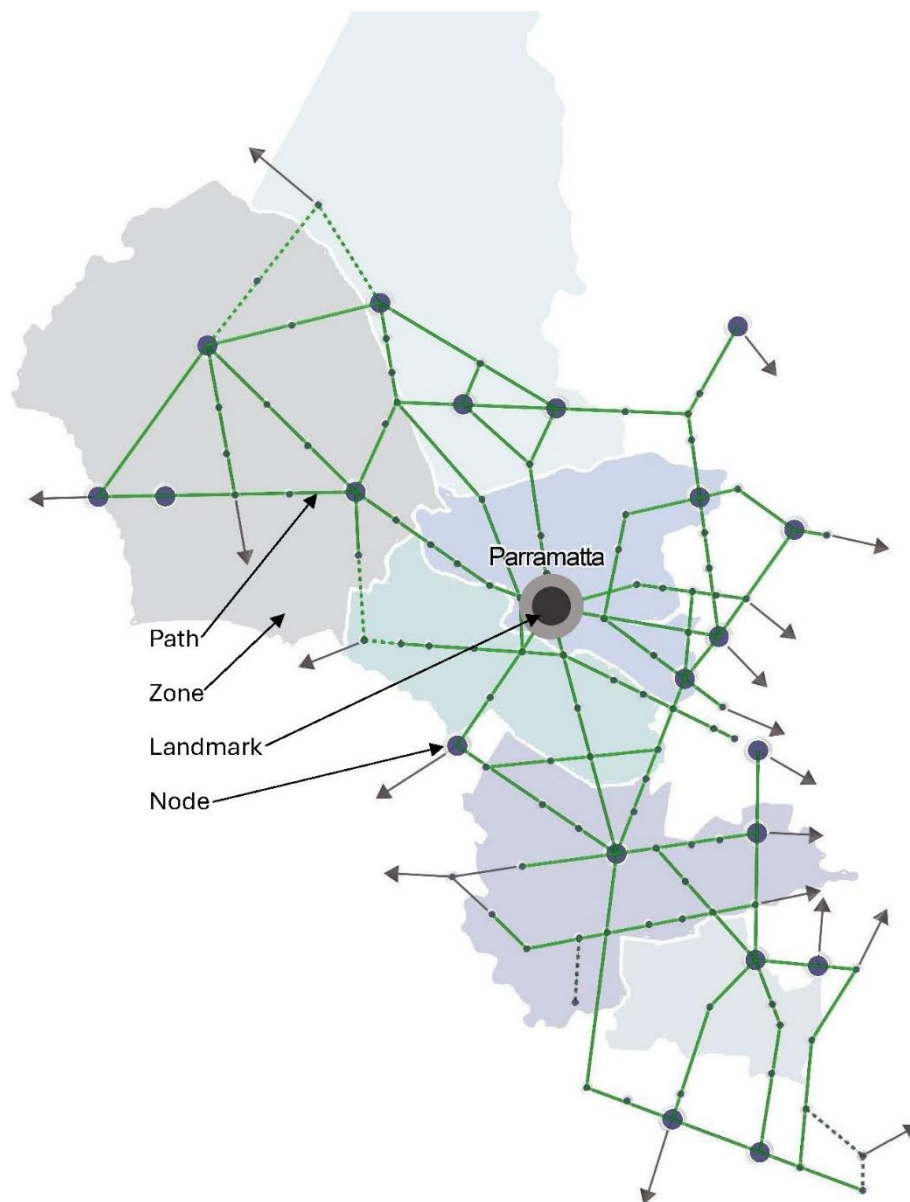


The chart above shows the summary of artefact evaluation against stakeholders' requirements set out in the adjusted Calibration tables 1 and 2 whilst using the same Calibration table 3. Based on the given artefact and the geometry count, the artefact was measured with a Score and a Rating. The blue bars mean Artefact 4 is rated as acceptable to urban designer, pedestrian and motor vehicle driver stakeholder, whilst the orange bars mean the artefact is rated as inappropriate for city planner, engineer, micromobility device user and building owner stakeholders.

As such, based on the Available Data Value = 13.2, and the Visible Element Data = 4 of Artefact 4, the Result shows the artefact's score and rating for each stakeholder in the evaluation table shown in Sub-Section 4.5.8.

#### 4.5.5 TEST 1 – Artefact 4

Test 1 Artefact 4 presents a variation to the graphical data in Artefact 4 and is customised to improve its performance for the *urban designer* stakeholder based on Calibration Table 1. The test artefact is a rendition of Artefact 4 to demonstrate the graphic transformation of geometry based on the original artefact geometry.



**Figure 4.58:** Test 1-Artefact 4

**Table 4.71: Test 1 Artefact 4 geometry count**

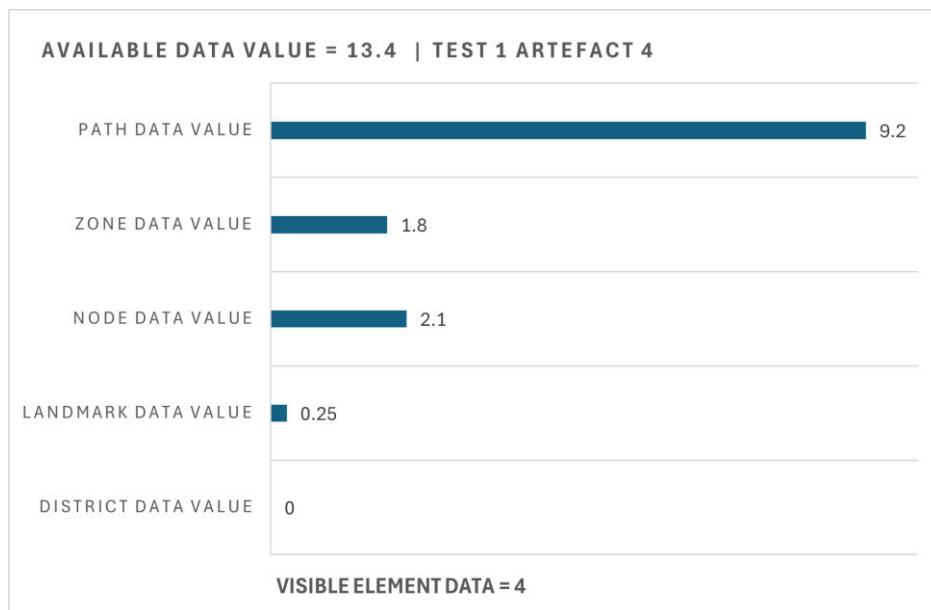
	Shape	Label	Weight
<i>Path-road</i>	0	0	0
<i>Path-motor vehicle</i>	0	0	0
<i>Path-pedestrian</i>	0	0	0
<i>Path-micro device</i>	U1=35	V1=17	W1=5
<i>Zone-pedestrian</i>	0	0	0
<i>Zone-motor vehicle</i>	0	0	0
<i>Zone-micro device</i>	U2=6	0	W2=6
<i>Node-micro device</i>	U0=20	0	W0=2
<i>Landmark-micro</i>	U0=1	V0=1	W0=2
<i>District-micro</i>	0	0	0

**TEST 1 ARTEFACT 4 SYSTEM ANALYSIS:**

The above table shows the geometry count for Test 1 Artefact 4. The result summary of the analysis for Test 1 Artefact 4 is shown below which shows that zone has been added. Landmark and district data have also been turned on, but edge has been turned off. The detailed analysis table is located in Sub-Section 4.5.8.

The System Analysis for the Test 1 Artefact 4 in Experiment 4 shows:

**Table 4.72: Test 1 Artefact 4 Analysis Summary**



**TEST 1 ARTEFACT 4 SYSTEM EVALUATION:**

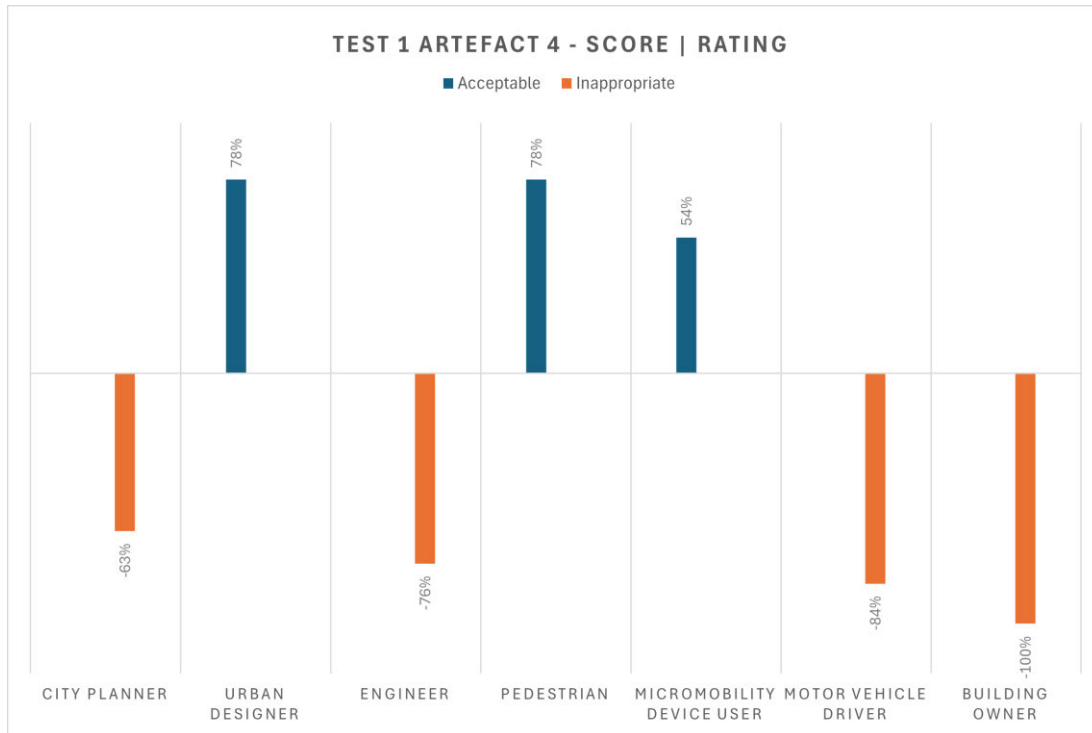
The System Evaluation for the Test 1-Artefact 4 in Experiment 4 shows:

The system evaluated the Artefact 4's statistical data analysis against the requirements set out for individual stakeholders. The system produced an autogenerated result as shown in the evaluation table in Sub-Section 4.5.8 for Test 1-Artefact 4 Evaluation.

The table shows the result of the evaluation for Test 1 Artefact 4 which shows a score of 78% Acceptability, an improvement based on the performance of Artefact 4 for urban designer of 57% Acceptability. It now also resulted in the artefact being acceptable to micromobility device user stakeholder but also changed from acceptable to inappropriate to motor vehicle driver stakeholder.

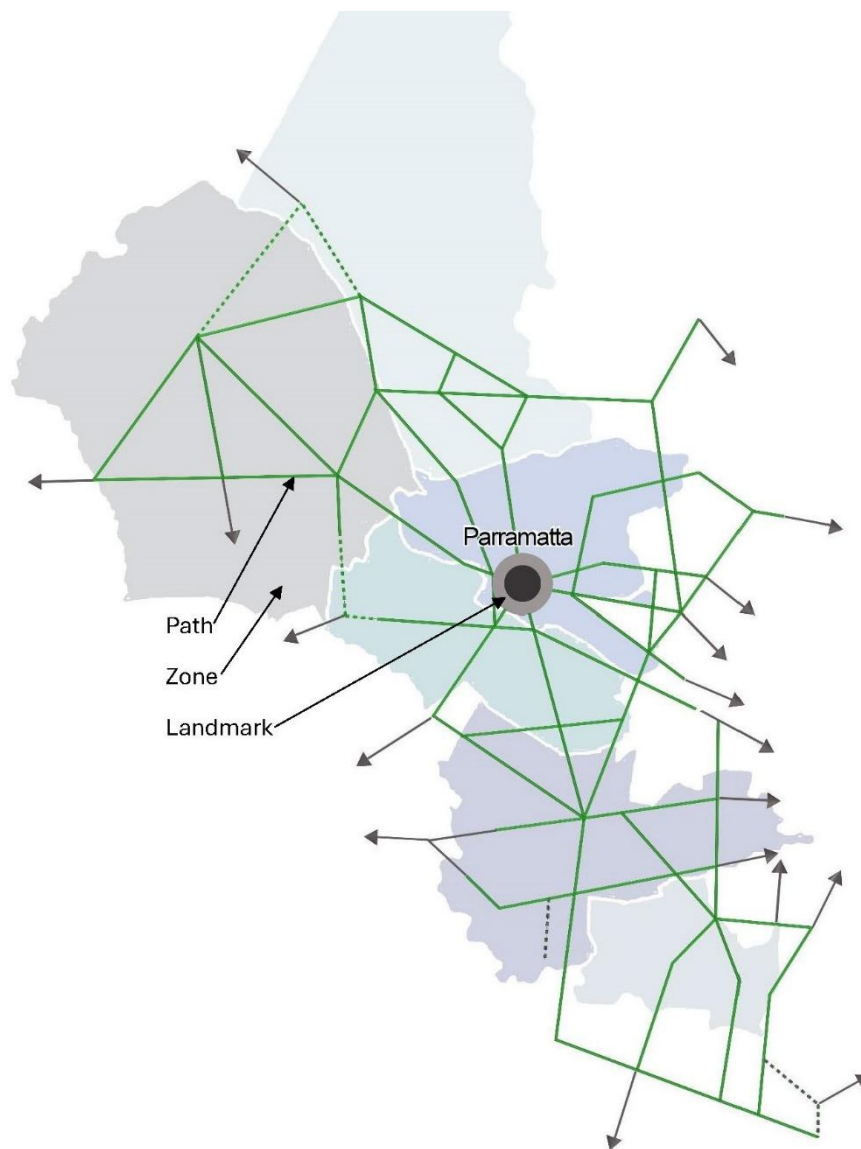
Based on the Available Data Value = 13.4, and the Visible Element Data = 4 of Test 1- Artefact 4, the summary of the Result is shown in the chart below for the artefact's score and rating for each stakeholder:

**Table 4.73: Test 1 Artefact 4 Evaluation Summary.**



#### 4.5.6 TEST 2 – Artefact 4

Test 2 Artefact 4 also presents another variation to the graphical data in Artefact 4 and is customised to improve its performance for the micromobility device user stakeholder. As a rendition of Artefact 4 the graphic transformation of geometry will be adjusted to meet the requirements for the micromobility device user set out in the adjusted Calibration table 1 and 2, whilst Calibration table 3 remains typical across all four experiments.



**Figure 4.59:** Test 2-Artifact 4.

With the view of improving the performance of Artefact 4 for the micromobility device user stakeholder, Test 2 Artefact 4 is an adjustment to the shapes used and the graphic information attribution. The aim is to eliminate the node data value to suit the requirements for micromobility device user stakeholder.

**Table 4.74: Test 2 Artefact 4 geometry count**

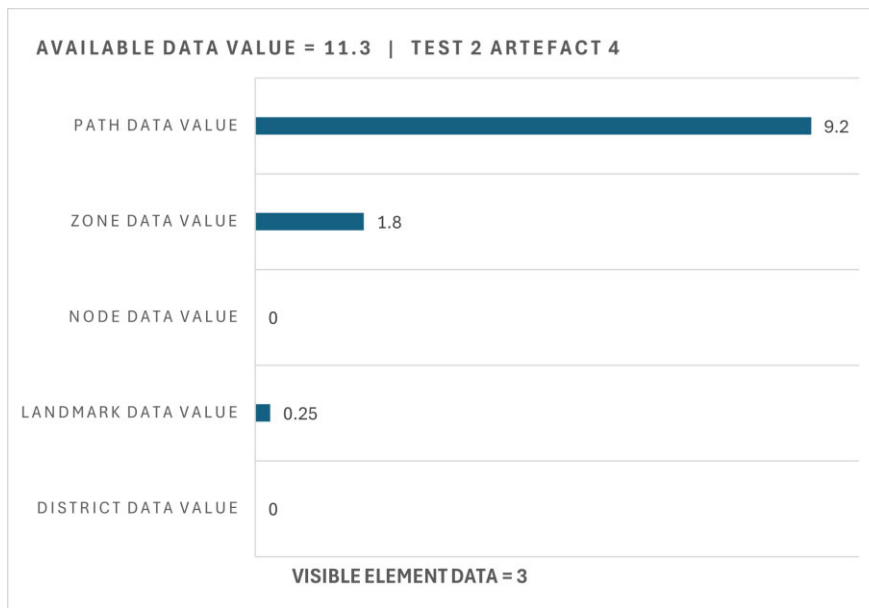
	Shape	Label	Weight
<i>Path-road</i>	0	0	0
<i>Path-motor vehicle</i>	0	0	0
<i>Path-pedestrian</i>	0	0	0
<i>Path-micro device</i>	U1=35	V1=17	W1=5
<i>Zone-pedestrian</i>	0	0	0
<i>Zone-motor vehicle</i>	0	0	0
<i>Zone-micro device</i>	U2=6	0	W2=6
<i>Node-micro device</i>	0	0	0
<i>Landmark-micro</i>	U0=1	V0=1	W0=2
<i>District-micro</i>	0	0	0

## TEST 2 ARTEFACT 4 SYSTEM ANALYSIS:

The result of the geometry count analysis is Visible Element Data is = 11.3 with the Available Data Value = 3, which are a decrease compared to Artefact 4.

### The System Analysis for the Test 2 Artefact 4 in Experiment 4:

**Table 4.75: Test 2 Artefact 4 Analysis Summary**



## TEST 2 ARTEFACT 4 SYSTEM EVALUATION:

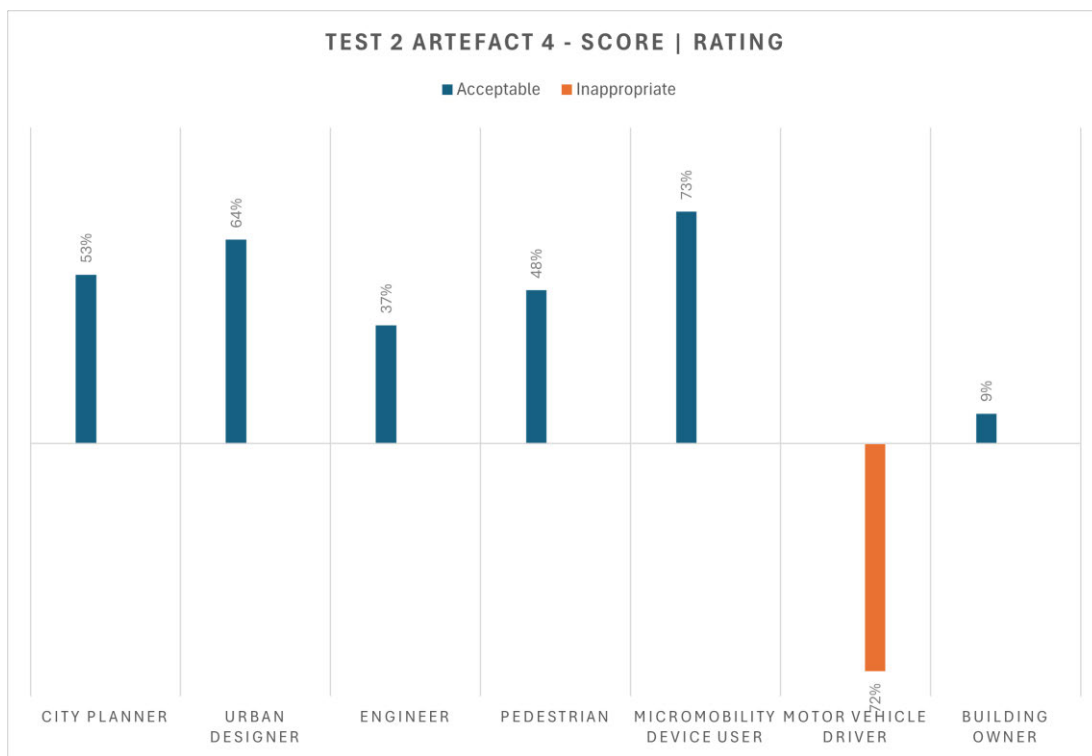
### The System Evaluation for the Test 2 Artefact 4 in Experiment 4:

The system evaluated the artefact's statistical data analysis against the requirements set out for individual stakeholders set out the adjusted Calibration table 1. The system produced an autogenerated result as shown in the evaluation table in Sub-Section 4.5.8 for Test 2 Artefact 4 Evaluation.

The table shows the result of the evaluation for Test 2 Artefact 4 which results in a great improvement on the performance of the artefact for micromobility device user stakeholder with an improved score from 74% Inappropriate in Artefact 4 to 73% Acceptable in Test 2 Artefact 4.

Based on the Available Data Value = 11.3 and the Visible Element Data = 3 of Test 2 Artefact 4, the summary of the Result is shown in the chart below for Test 2 Artefact 4 score and rating for each stakeholder:


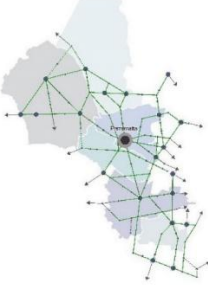
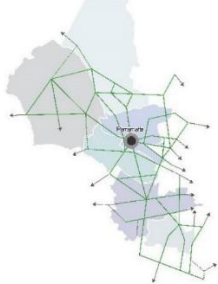
**Table 4.76: Test 2 Artefact 4 Evaluation Summary**



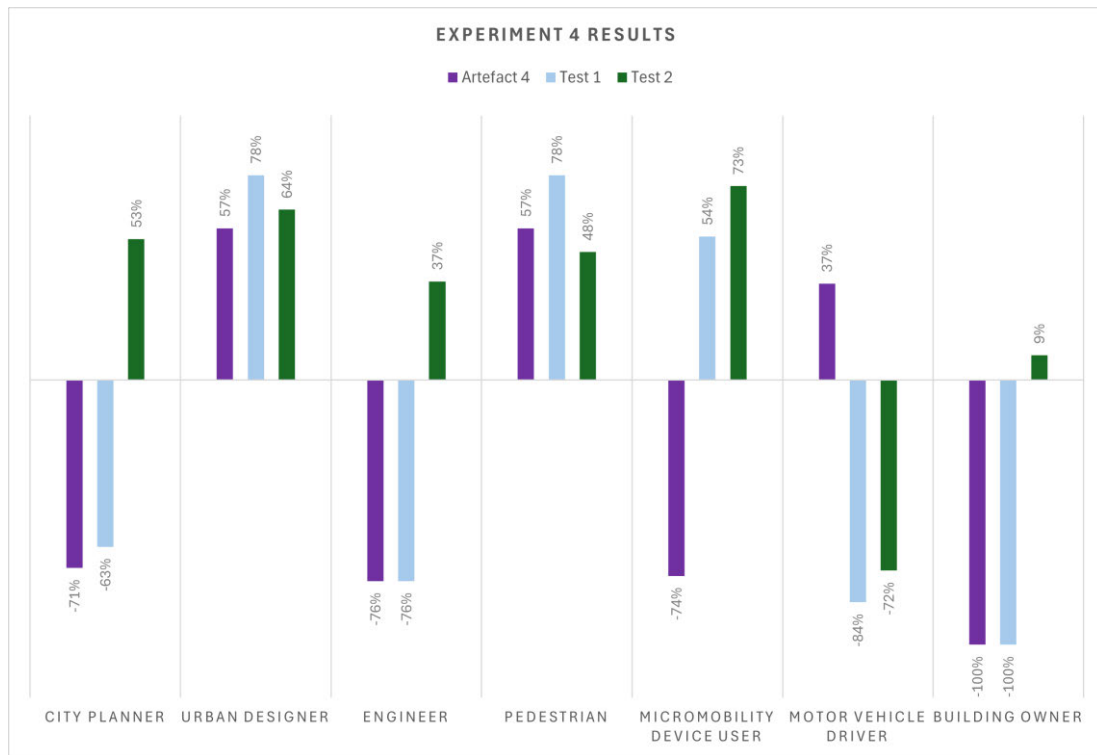
#### 4.5.7 PERFORMANCE RESULTS

This Sub-Section shows the results for Experiment 4. The results for artefact graphic comparison and the score and ranking for each for *urban designer* and for *micromobility device user* based on the parameters set out in the adjusted Calibration tables 1 and 2 and the same computation set out in Calibration table 3 are shown below. As well the overall results summary for Experiment 4 is summarised in the chart below and the overall performance comparison are set out below to illustrate the percentage data value and the percentage data failure for all three artefacts in Experiment 4.

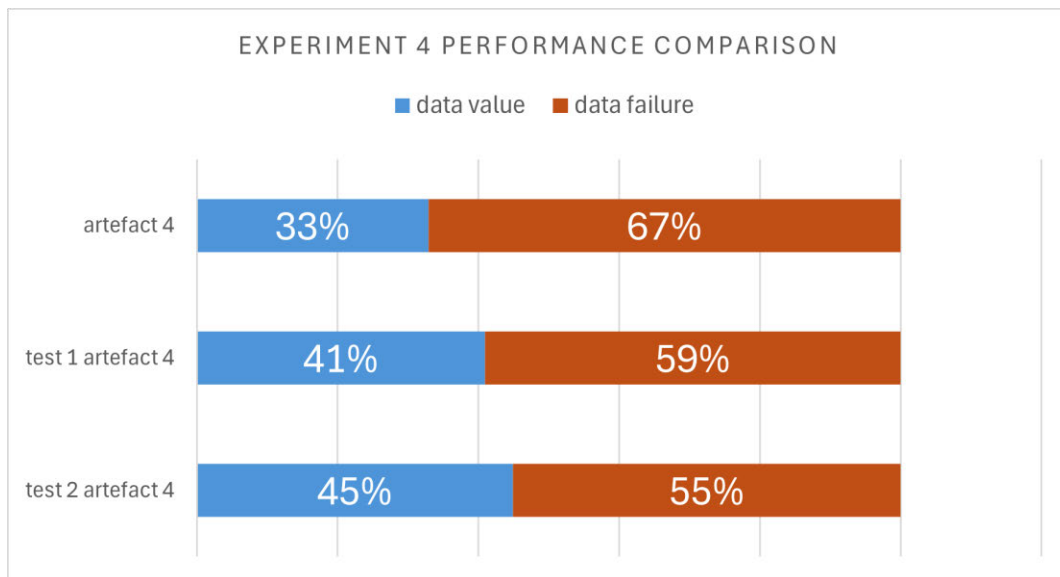
**Table 4.76: Test 2 Artefact 4 Evaluation Summary**

EXPERIMENT 4		urban designer	micromobility device user
ARTEFACT 4		57% Acceptable	74% Inappropriate
TEST 1 ARTEFACT 4		<b>78%</b> <b>Acceptable</b>	54% Acceptable
TEST 2 ARTEFACT 4		64% Acceptable	<b>73%</b> <b>Acceptable</b>

**Table 4.78: Experiment 4 Results Summary**




**Table 4.79: Experiment 4 Artefacts Performance Results**



## 4.5.8 ANALYSIS & EVALUATION TABLES

### Artefact 4 Analysis & Evaluation

Table 4.80: Artefact 4 Analysis



urban object	urban element	parameter	shape				label				weight				ANALYSIS Sum	drawing #4		
			u0	u1	u2	u3	v0	v1	v2	v3	w0	w1	w2	w3				
			point	line/ curve	plane	solid	text/ number/ symbol	line/ curve	plane	solid	point area	thickn ess/ colou	hatch/ colour	hatch/ colour				
0	road	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			weighting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	motor vehicle	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			weighting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	pedestrian	path	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			weighting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	micromobility device	path	visibility	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0
			weighting	0	35	0	0	0	2	0	0	0	5	0	0	0	0	0
			amount	0	7	0	0	0	0.2	0	0	0	0.5	0	0	0	0	7.7
1	1																	7.7 PATH DATA VALUE
0	road	edge	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			weighting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	pedestrian	edge	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			weighting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	micromobility device	edge	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			weighting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0																	0.0 EDGE DATA VALUE
0	pedestrian	zone	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			weighting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	motor vehicle	zone	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			weighting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	micromobility device	zone	visibility	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			weighting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
			amount	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0																	0.0 ZONE DATA VALUE
1	micromobility device	node	visibility	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0
			weighting	20	0	0	0	20	0	0	0	2	0	0	0	0	0	0
			amount	2	0	0	0	1	0	0	0	0.1	0	0	0	0	0	3.1
1	1																	3.1 NODE DATA VALUE
1	micromobility device	landmark	visibility	1	0	0	0	1	0	0	0	1	0	1	0	0	0	0
			weighting	1	0	0	0	1	0	0	0	2	0	3	0	0	0	0
			amount	0.1	0	0	0	0.05	0	0	0	0.1	0	0.3	0	0	0	0.6
1	1																	0.6 LANDMARK DATA VALUE
1	micromobility device	district	visibility	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0
			weighting	0	0	1	0	0	0	1	0	0	0	3	0	0	0	0
			amount	0	0	0.2	0	0	0	0.1	0	0	0	0.3	0	0	0	0.6
1	1																	0.6 DISTRICT DATA VALUE
4	VISIBLE ELEMENT DATA															12.0	AVAILABLE DATA VALUE (AD)	
5	REQUIRED ANALYSED DATA																	

**Table 4.81: Artefact 4 Evaluation**

EVALUATION										
System calculates:										
urban object-urban element	urban element visibility	city planner	urban designer	engineer	pedestrian	micromobility device user	motor vehicle driver	building owner		
road-path	0	-1	-1	-1	-1	-1	-1	0		
motor vehicle-path	0	-1	-1	-1	-1	-1	-1	0		
pedestrian-path	0	-1	-1	-1	-1	-1	-1	0		
micromobility device-path	1	0	0	0	0	0	0	-1		
DATA PENALTY		-3	-3	-3	-3	-3	-3	-3	-1	
PATH DATA VALUE LESS PENALTY		4.7	4.7	4.7	4.7	4.7	4.7	4.7	-1	
ELEMENT PENALTY		0	0	0	0	0	0	0	-1	
road-edge	0	0	0	0	0	0	0	0		
pedestrian-edge	0	0	0	0	0	0	0	0		
micromobility device-edge	0	0	0	0	0	0	0	0		
DATA PENALTY		0	0	0	0	0	0	0	0	
EDGE DATA VALUE LESS PENALTY		0	0	0	0	0	0	0	0	
ELEMENT PENALTY		0	0	0	0	0	0	0	0	
pedestrian-zone	0	-1	-1	0	-1	-1	0	-1		
motor vehicle-zone	0	-1	-1	0	-1	-1	0	-1		
micromobility device-zone	0	-1	-1	0	-1	-1	0	-1		
DATA PENALTY		-3	-3	0	-3	-3	0	-3	-1	
ZONE DATA VALUE LESS PENALTY		-1	-1	0	-1	-1	0	-1	-1	
ELEMENT PENALTY		-1	-1	0	-1	-1	0	-1	-1	
micromobility device-node	1	-1	0	-1	0	-1	-1	-1		
DATA PENALTY		-1	0	-1	0	-1	-1	-1	-1	
NODE DATA VALUE LESS PENALTY		-1	3.1	-1	3.1	-1	-1	-1	-1	
ELEMENT PENALTY		-1	0	-1	0	-1	-1	-1	-1	
micromobility device-landmark	1	-1	0	-1	0	-1	-1	0		
DATA PENALTY		-1	0	-1	0	-1	-1	0	0	
LANDMARK DATA VALUE LESS PENALTY		-1	0.55	-1	0.55	-1	0.55	-1	0.55	
ELEMENT PENALTY		-1	0	-1	0	-1	-1	0	0	
micromobility device-district	1	0	-1	-1	-1	-1	0	-1		
DATA PENALTY		0	-1	-1	-1	-1	0	-1	-1	
DISTRICT DATA VALUE LESS PENALTY		0.6	-1	-1	-1	-1	0.6	-1	-1	
ELEMENT PENALTY		0	-1	-1	-1	-1	0	-1	-1	
<b>SCORING</b>										
STAKEHOLDER DATA VALUE		2.3	6.35	1.7	6.35	2.25	3.3	-3.45		
VALUABLE DATA		19%	53%	14%	53%	19%	28%	-29%		
<b>RATING</b>										
REQUIRED ELEMENT DATA		3	4	1	4	3	2	2		
TOTAL ELEMENT PENALTY		-3	-2	-3	-2	-3	-2	-4		
ELEMENT DATA FAILURE		60%	40%	60%	40%	60%	40%	80%		
Rated As:		Inappropriate	Acceptable	Inappropriate	Acceptable	Inappropriate	Acceptable	Inappropriate		
<b>RESULT</b>		<b>81%</b>	<b>53%</b>	<b>86%</b>	<b>53%</b>	<b>81%</b>	<b>28%</b>	<b>100%</b>		
		Inappropriate	Acceptable	Inappropriate	Acceptable	Inappropriate	Acceptable	Inappropriate		



**Table 4.83: Test 1-Artifact 4 Evaluation**

EVALUATION															
System calculates:															
urban object-urban element	urban element visibility	city planner		urban designer		engineer		pedestrian		micromobility device user		motor vehicle driver		building owner	
road-path	0	-1		-1		-1		-1		-1		-1		0	
motor vehicle-path	0	-1		-1		-1		-1		-1		-1		0	
pedestrian-path	0	-1		-1		-1		-1		-1		-1		0	
micromobility device-path	1	0		0		0		0		0		0		-1	
DATA PENALTY		-3		-3		-3		-3		-3		-3		-1	
PATH DATA VALUE LESS PENALTY		6.2		6.2		6.2		6.2		6.2		6.2		-1	
ELEMENT PENALTY		0		0		0		0		0		0		-1	
road-edge	0	0		0		0		0		0		0		0	
pedestrian-edge	0	0		0		0		0		0		0		0	
micromobility device-edge	0	0		0		0		0		0		0		0	
DATA PENALTY		0		0		0		0		0		0		0	
EDGE DATA VALUE LESS PENALTY		0		0		0		0		0		0		0	
ELEMENT PENALTY		0		0		0		0		0		0		0	
pedestrian-zone	0	-1		-1		0		-1		-1		0		-1	
motor vehicle-zone	0	-1		-1		0		-1		-1		0		-1	
micromobility device-zone	1	0		0		-1		0		0		-1		0	
DATA PENALTY		0		0		-1		0		0		-1		0	
ZONE DATA VALUE LESS PENALTY		1.8		1.8		-1		1.8		1.8		-1		1.8	
ELEMENT PENALTY		0		0		-1		0		0		-1		0	
micromobility device-node	1	-1		0		-1		0		-1		-1		-1	
DATA PENALTY		-1		0		-1		0		-1		-1		-1	
NODE DATA VALUE LESS PENALTY		-1		2.1		-1		2.1		-1		-1		-1	
ELEMENT PENALTY		-1		0		-1		0		-1		-1		-1	
micromobility device-landmark	1	-1		0		-1		0		0		-1		0	
DATA PENALTY		-1		0		-1		0		0		-1		0	
LANDMARK DATA VALUE LESS PENALTY		-1		0.25		-1		0.25		0.25		-1		0.25	
ELEMENT PENALTY		-1		0		-1		0		0		-1		0	
micromobility device-district	0	-1		0		0		0		0		-1		0	
DATA PENALTY		-1		0		0		0		0		-1		0	
DISTRICT DATA VALUE LESS PENALTY		-1		0		0		0		0		-1		0	
ELEMENT PENALTY		-1		0		0		0		0		-1		0	
<b>SCORING</b>															
STAKEHOLDER DATA VALUE		5		10.35		3.2		10.35		7.25		2.2		0.05	
VALUABLE DATA		37%		78%		24%		78%		54%		16%		0%	
<b>RATING</b>															
REQUIRED ELEMENT DATA		3		4		1		4		3		2		2	
TOTAL ELEMENT PENALTY		-3		0		-3		0		-1		-4		-2	
ELEMENT DATA FAILURE		75%		0%		75%		0%		25%		100%		50%	
Rated As:		Inappropriate		Acceptable		Inappropriate		Acceptable		Acceptable		Inappropriate		Inappropriate	
RESULT		63%		78%		76%		78%		54%		84%		100%	
		Inappropriate		Acceptable		Inappropriate		Acceptable		Acceptable		Inappropriate		Inappropriate	



**Table 4.85: Test 2-Artifact 4 Evaluation**

EVALUATION																						
System calculates:																						
urban object-urban element	urban element visibility	city planner			urban designer			engineer			pedestrian		micromobility device user		motor vehicle driver		building owner					
road-path	0	-1			-1			-1			-1			-1			-1			0		
motor vehicle-path	0	-1			-1			-1			-1			-1			-1			0		
pedestrian-path	0	-1			-1			-1			-1			-1			-1			0		
micromobility device-path	1	0			0			0			0			0			0			-1		
DATA PENALTY		-3			-3			-3			-3			-3			-3			-1		
PATH DATA VALUE LESS PENALTY		0	6.2		0	6.2		0	6.2		0	6.2		0	6.2		0	6.2		-1		-1
ELEMENT PENALTY		0			0			0			0			0			0			-1		
road-edge	0	0			0			0			0			0			0			0		
pedestrian-edge	0	0			0			0			0			0			0			0		
micromobility device-edge	0	0			0			0			0			0			0			0		
DATA PENALTY		0			0			0			0			0			0			0		
EDGE DATA VALUE LESS PENALTY		0	0		0	0		0	0		0	0		0	0		0	0		0	0	0
ELEMENT PENALTY		0			0			0			0			0			0			0		0
pedestrian-zone	0	-1			-1			0			-1			-1			0			-1		
motor vehicle-zone	0	-1			-1			0			-1			-1			0			-1		
micromobility device-zone	1	0			0			-1			0			0			-1			0		
DATA PENALTY		0			0			-1			0			0			-1			0		
ZONE DATA VALUE LESS PENALTY		0	1.8		0	1.8		-1	-1		0	0		0	1.8		-1	-1		0	1.8	
ELEMENT PENALTY		0			0			-1			0			0			-1			0		
micromobility device-node	0	0			-1			0			-1			0			0			0		
DATA PENALTY		0			0			-1			-1			0			0			0		
NODE DATA VALUE LESS PENALTY		0	0		0	-1		0	0		-1	-1		0	0		0	0		0	0	0
ELEMENT PENALTY		0			0			0			-1			0			0			0		0
micromobility device-landmark	1	-1			0			-1			0			0			-1			0		
DATA PENALTY		-1			0			-1			0			0			-1			0		
LANDMARK DATA VALUE LESS PENALTY		-1	-1		0	0.25		-1	-1		0	0.25		0	0.25		-1	-1		0	0.25	
ELEMENT PENALTY		-1			0			-1			0			0			-1			0		
micromobility device-district	0	-1			0			0			0			0			-1			0		
DATA PENALTY		-1			0			0			0			0			-1			0		
DISTRICT DATA VALUE LESS PENALTY		-1	-1		0	0		0	0		0	0		0	0		-1	-1		0	0	0
ELEMENT PENALTY		-1			0			0			0			0			-1			0		
<b>SCORING</b>																						
STAKEHOLDER DATA VALUE		6		7.25			4.2			5.45		8.25		3.2		1.05						
VALUABLE DATA		53%		64%			37%			48%		73%		28%		9%						
<b>RATING</b>																						
REQUIRED ELEMENT DATA		3		4			1			4		3		2		2						
TOTAL ELEMENT PENALTY		-2		-1			-2			-1		0		-3		-1						
ELEMENT DATA FAILURE		40%		20%			40%			20%		0%		60%		20%						
Rated As:		Acceptable		Acceptable			Acceptable			Acceptable		Acceptable		Inappropriate		Acceptable						
<b>RESULT</b>		<b>53%</b>		<b>64%</b>			<b>37%</b>			<b>48%</b>		<b>73%</b>		<b>28%</b>		<b>9%</b>						
		<b>Acceptable</b>		<b>Acceptable</b>			<b>Acceptable</b>			<b>Acceptable</b>		<b>Acceptable</b>		<b>Inappropriate</b>		<b>Acceptable</b>						



# Chapter 5: Results & Findings

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## 5.1 INTRODUCTION

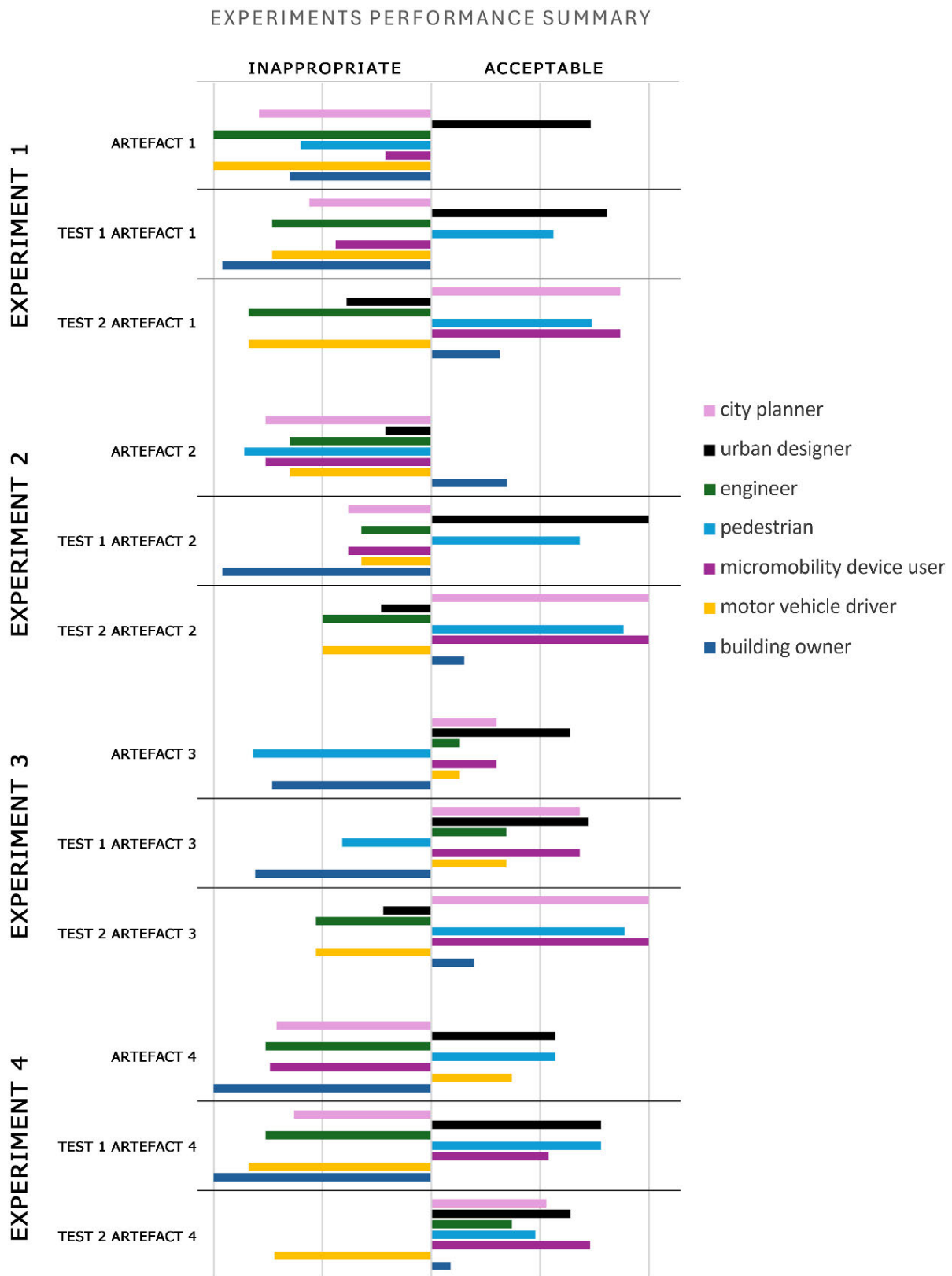
This chapter presents the results and findings of the experiment conducted in Chapter 4, with a detailed discussion provided in Section 5.2, titled "Experiment Results." To facilitate comprehension, graphs are employed to summarise and visually represent the overall outcomes of the four experiments. Initial general assumptions are drawn from the visual characteristics of these graphs, which are subsequently followed by a series of analytical discussions.

Sub-Section 5.2.1 examines the impact and relevance of artefacts concerning stakeholders, while Sub-Section 5.2.2 delves into the effects of shape, label, and weight on the statistical data analysis of these artefacts. Sub-Section 5.2.3 addresses the use of calibration tables, evaluating their influence on the results and assessing the effectiveness of Boolean mapping in reflecting real-world conditions. This section also discusses how well the theoretical framework provided by Kevin Lynch's urban elements of path, edge, node, landmark and district impacts the experiment's findings. Additionally, the calibration process for evaluating data values and the application of penalties, as well as the mapping calibration related to shape, weight, and label, are critically analysed.

Further findings are presented in Section 5.3. Sub-Section 5.3.1 discusses the implementation of Algorithmic Aesthetic Theory within the experimental schema. Sub-Section 5.3.2 explores the digital tools utilised in the research. Sub-Section 5.3.3 focuses on the application of Lynch's theory of urban elements—path, edge, node, landmark, and district—for theoretical mapping. Lastly, Sub-Section 5.3.4 examines the selected artefacts (Artefacts 1 to 4) to illustrate the operational functionality of the system.

## 5.2 EXPERIMENT RESULTS

Table 5.1: Results Summary of Experiments 1 to 4



To summarise and compare the multiple evaluation sets from Experiments 1 to 4, the condensed results have been translated as shown in Table 5.1. An examination of this graphical representation provides valuable insights into the performance of the artefacts evaluated under specific conditions defined by the calibration tables. This visualisation enhances understanding of the communicative value of the artefacts and validates several assumptions regarding the evaluation method and the influence of artefacts on stakeholder communication. Importantly, the graph reveals recognisable patterns that facilitate the formulation of general assumptions. These patterns not only illustrate the artefacts' effectiveness but also highlight the nuances in stakeholder interactions, underscoring the critical assumptions on visual communication artefacts. To delineate the fundamental features of the data, the following connections and assumptions are derived from the visual characteristics of the graph. These reference the calibration conditions established in Chapter 4. By synthesising these insights, an understanding of how the artefacts perform within the defined parameters and are presented below.

### **5.2.1 GRAPHICAL EVALUATION METHOD COMPATIBILITY WITH 2D ARTEFACTS**

The evaluation method used in Experiments 1 to 4 demonstrated that assessments of various types of 2D artefacts, including plans and elevations, can be effectively conducted using the same consistent statistical analysis framework. Notably, Experiment 3, which focuses on an elevation view, can be analysed similarly to the plan views explored in Experiments 1, 2, and 4. This is suggested in the graph as consistency across all four experiments is exhibited showing analogous patterns of progression from "Inappropriate" to "Acceptable" performance as illustrated in the results for Artefacts through Tests 1 and 2

Moreover, the findings indicate that both small-scale urban design areas and larger geographic urban design contexts can be evaluated through the same analytical lens. This is evidenced by Experiment 4, which features an artefact involving a large geographic area, and reveals similar patterns to those identified in Experiments 1-3, which focus on smaller-scale designs.

The graph further illustrates that while Experiment 2 involves artefacts characterised by more technical detail, Experiment 4 features artefacts with less complexity, yet both can be evaluated objectively within the same framework. This supports the notion that various drawing styles can undergo objective evaluation using the same system.

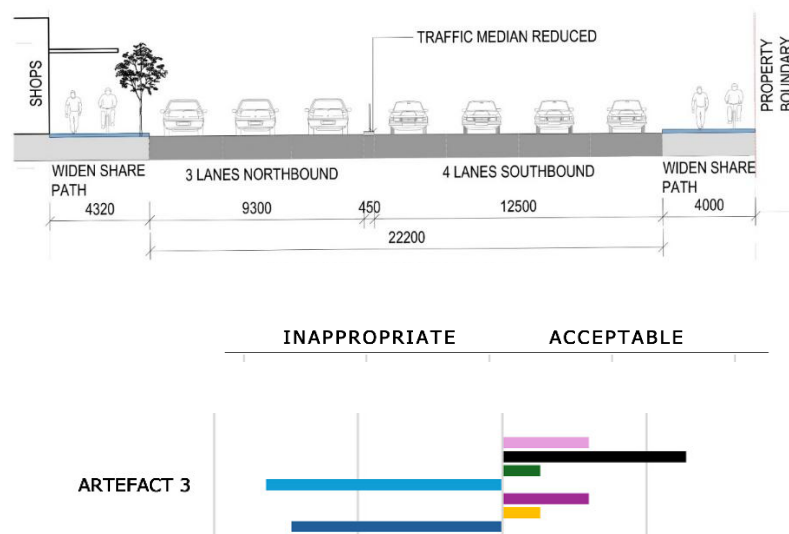
It can also be concluded that the use of graphical analysis provides quantifiable information that can be used to measure and evaluate visual performance for a given audience with a set of prescribed requirements. The statistical data analysis of shapes and graphical information attributes appears coherent across all four experiments, reinforcing the validity of the evaluation method employed.

## **5.2.2 SYSTEM ADAPTABILITY TO MULTIPLE AND DIVERSE STAKEHOLDER REQUIREMENTS**

General assumptions on the performance relating to communicative effectiveness of the artefact can also be derived from the above graph. The morphology from the original Artefact, to Test 1 and to Test 2 versions of the artefact shows there is a trend of improvement across all four experiments. This signifies that intentionally altering the artefact's statistical graphical data values to match prescribed stakeholder requirement Boolean values will improve results.

The graph also reveals that the original Artefacts on plan view are mainly inappropriate to most stakeholders as can be observed in Experiments 1, 2 and 4. Artefacts. These

experiments show more Inappropriate to the left of the graph line values. Whereas the artefact with elevation view in Experiment 3 is generally acceptable to five out of seven stakeholders as it has more values right of the graph line. It also shows that the micromobility device user stakeholder best relates with elevation views. This is illustrated in Experiment 3 for Artefact, Test 1 and Test 2 showing as Acceptable values right of the graph line for micromobility device user stakeholder.



**Figure 5.1:** Artefact 3 and rating of Acceptable for 5 out of 7 stakeholders

The four experiments have a total of 12 artefact analyses and evaluations. Based on this, it shows that out of the stakeholders, engineer and building owner stakeholders fared the least, as the graph shows that 9 out of 12 evaluations are showing left of the graph line Inappropriate for the engineer and building owner stakeholders. Similarly, it can be observed that urban designer and pedestrian stakeholders fared better compared to other stakeholders, as 8 out of 12 evaluations are showing as right of the graph line Acceptable for urban designer and pedestrian stakeholders.

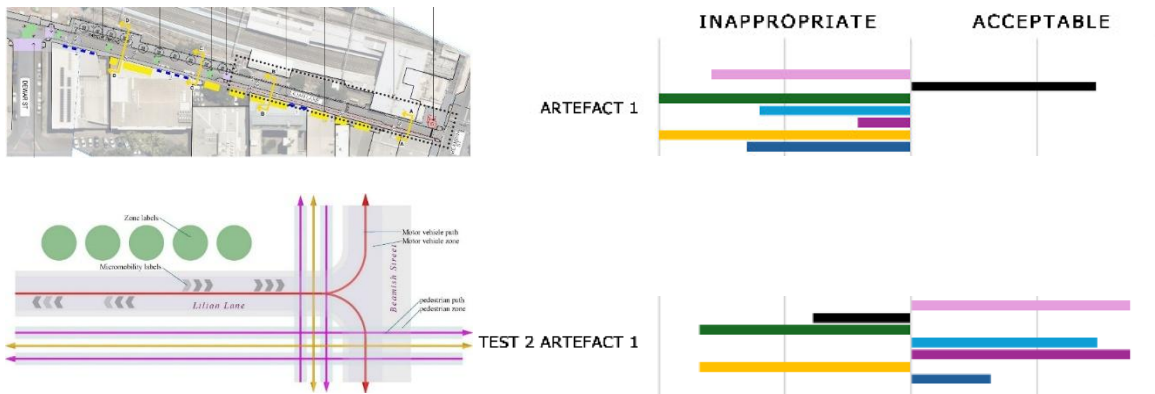
Generally, the four original Artefacts from all four experiments best served the urban designer stakeholder, including the performance of Artefact in Experiment 2. Although Artefact 2 in Experiment 2 is showing value of Inappropriate left of the graph line, it is shorter

which means it has the least inappropriate value and ranks as second place after the building owner stakeholder which shows as the only Acceptable right of the graph line value.

It can also be observed that the six evaluations in Experiment 1 and 2 do not meet the needs of engineer and motor vehicle driver stakeholders, as they are all shown to be left of the graph line Inappropriate. Interestingly, Artefact 3 in Experiment 3 which features the elevation view is only less than 50% Acceptable to engineer and motor vehicle driver stakeholder.

The patterns of the graph also show that improving artefacts for urban designer stakeholder has a positive impact on pedestrian stakeholder, whilst it has a negative impact on building owner stakeholder. This can be observed in the graphical changes made from the original Artefact to the constructed Test 1 across all four experiments. Recall that Test 1 is an altered version of the original Artefact in an attempt to closely match the urban designer requirements Boolean values. The results are shown in the graphs illustrating that pedestrian stakeholder as well as urban designer stakeholder have improved values due to the graphical changes made from the original Artefact to Test 1 across all four experiments. This has the opposite effect on building owner stakeholder where values worsen with the changes made across all four experiments. Observe figure 5.2 which improved the acceptability rating of the artefact for the pedestrian stakeholder in light blue with changes made to the original Artefact 1 resulting in the Test 2 version. The changes included the addition of pedestrian paths and walking zones in Test 2 that were missing in the original Artefact 1.

It also shows that visual communication for non-domain experts such as pedestrian, micromobility device user, motor vehicle driver and building owner stakeholders cannot be generalised or simplified as performance has mixed results.



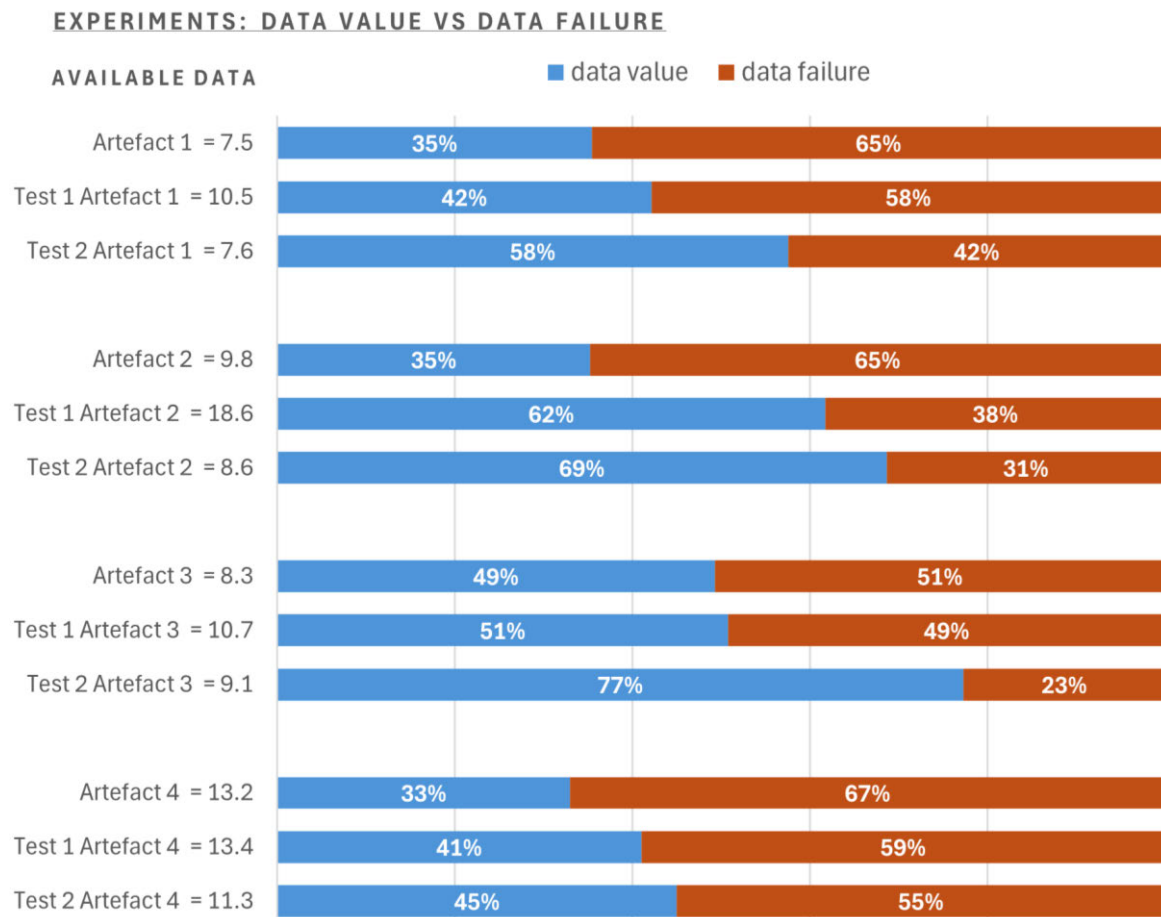
**Figure 5.2:** Improving the rating for pedestrian stakeholder in light blue.

### 5.2.3 COMPLEX RELATIONSHIP OF AVAILABLE DATA AND DATA VALUE

The bar graph represents the visual results of Experiments 1 to 4 in terms of the amount of *Data Value* and the amount of what is considered as *Data failure* contained in each artefact that were evaluated. The graph shows the amount of *Available Data* contained in the artefact in terms of information about urban design elements and the statistical data analysis used in the research and explained in Chapter 3.

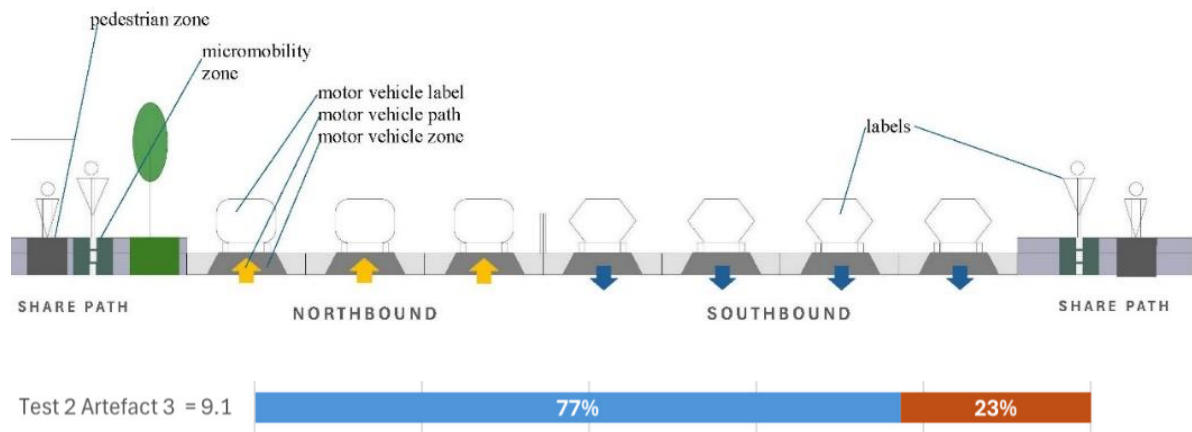
In Table 5.2, *Data Value* represents information that enhances the communication of urban design relevant to the identified stakeholders. Conversely, *Data Failure* denotes information deemed not valuable, negatively impacting urban design communication. This failure arises from either insufficient data or excessive, irrelevant information that does not meet stakeholder needs.

**Table 5.2: Summary Data Value and Data Failure in Experiments 1 - 4**



Graph 2 illustrates that Test 2 Artefact 3, which features an elevation view, possesses the highest Data Value at 77%, despite containing only 9.1 of Available Data. This sample proves to be the most effective for stakeholders in comparison to others. In contrast, Test 1 Artefact 2, which employs a plan view with a map underlay, has a significantly higher Available Data of 18.6 but only achieves a Data Value of 62%. This discrepancy highlights a lack of correlation between the amount of graphical data in artefacts and their effectiveness in urban design communication for stakeholders. Additionally, a comparison between Artefacts 1 and 2 reveals that both have a Data Value of 35%, yet they contain differing amounts of Available Data, further emphasising the complex relationship between data quantity and communicative efficacy. Artefact 2 which presents as the more technical compared with the other artefacts and

has the most potential for improvement. It has 35% valuable data and shows that it is the most improved by 34% increase as shown in Test 2 Artefact 2 with a total 69% valuable data and the second best performing across all artefacts even if it only has low *Available Data* of 9.1.

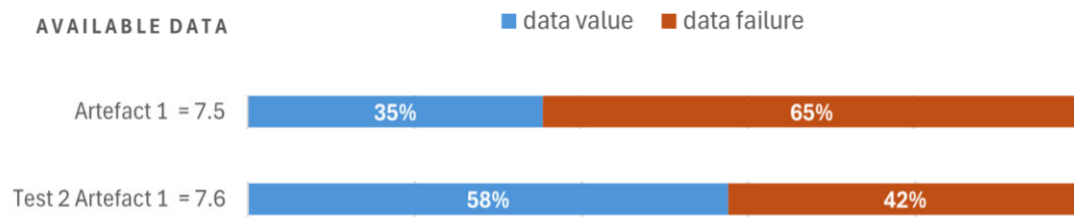


**Figure 5.3:** Test 2 Artefact 3 shows the highest Data Value of 77% with the lowest Data Failure of 23%, and is highly Acceptable to city planner, pedestrian and micromobility device user stakeholders

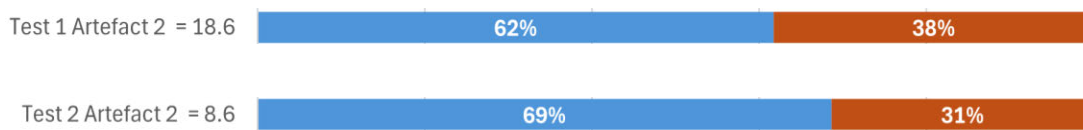
Experiment 4 with Artefact 4 and Tests 1 and 2 have the most *Data failure* combined, as compared to other experiments. Whilst Experiment 3 which features an elevation view with Artefact 3 and Tests 1 and 2 versions have the least *Data failure* combined.

It can also be recognised that graphical count represented by the *Available Data* amount does not directly correlate with communicative performance as illustrated in valuable data of *Data Value* percentages and inappropriate data of *Data failure* percentages. Observe Example 1. Artefact 1 = 7.5 Available Data is close to Test 2 = 7.6 Available Data. However, Artefact 1 has 35% Data Value, whilst Test has much greater Data Value at 58%. Similarly, observe Example 2. Test 1 = 18.6 has a very high Available Data content compared to Test 2 = 8.6 Available Data. However, Test 1 has a 62% Data Value which is a very close amount of 69% Data Value for Test 2.

## Example 1



## Example 2



**Figure 5.4:** No Relationship between Available Data and Data Value

The general assumptions above were based on the visual characteristics of the simplified graphs after careful scrutiny. They underscore observed phenomena on the relationships of nominal data of artefacts, stakeholders, and data values, and any correlations that were derived from it.

Based on the experiments on artefact performance and the conditions set out in Calibration tables 1 to 3, the graphs validate the following narratives:

- Artefacts impact can be categorically measured.
- Artefact visual data relevance can be measured based on stakeholders' specific needs.
- Statistical data on shapes and graphical attributes can inform how artefacts can be altered as a targeted intervention.

## 5.2.4 RESULTS FROM ARTEFACT VS STAKEHOLDER RELEVANCY

### 5.2.4.1 Experiment 1

Artefact 1 is a visualisation on plan view that features a map underlay used in the urban design development involving a micromobility infrastructure project. As shown in Graph 1, the Experiments Performance Summary chart, the performance of Artefact 1 shows it is only right of the graph line Acceptable for urban designer stakeholder and left of the graph line Inappropriate for the rest of the stakeholders. This result is based on the conditions set out in the analysis and criteria set out in the evaluation of the research. It also shows in Graph 2, the Data Value vs Data Failure graph, that Artefact 1 contains 7.5 Available Data, 65% of which is considered as Data Failure, a portion that does not meet stakeholders' requirements.

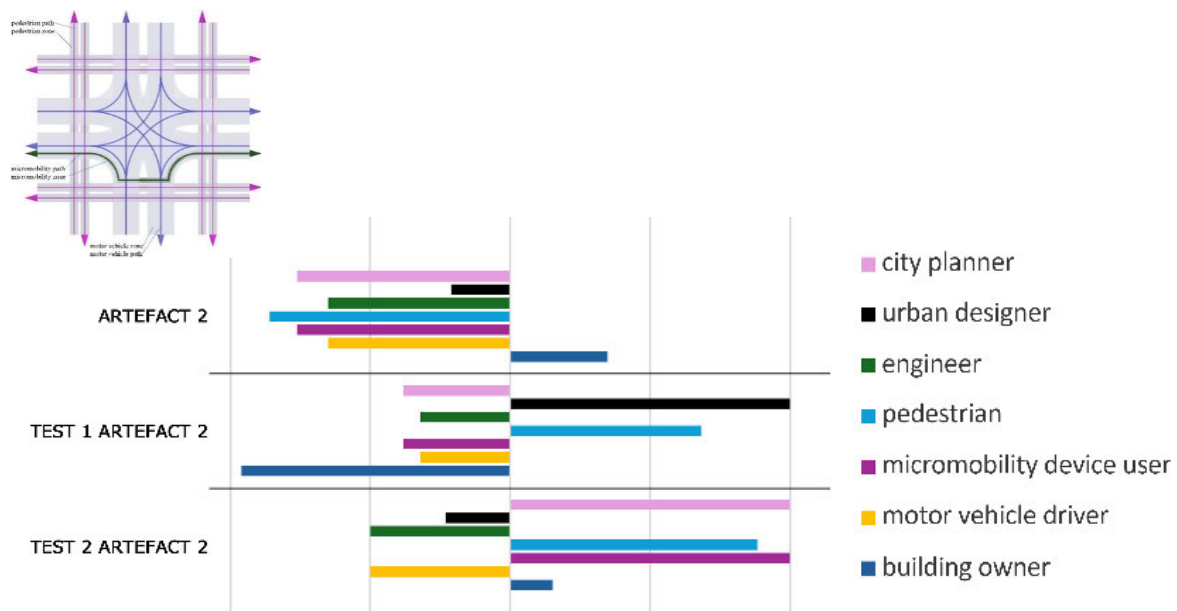
Test 1 Artefact 1 modulates the score to match the urban designer stakeholder Boolean values. Based on Graph 1, the results show improvements for all stakeholders except for micromobility device user stakeholder, which is worse, indicated by the greater left of the graph line Inappropriate value. As well, in Graph 2, it shows that Test 1 Artefact 1 has increased in Available Data from 7.5 to 10.5 which resulted in increased Data Value from 35% to 42%.

Interestingly, Test 2 Artefact 1 which modulates the score to match micromobility device user stakeholder Boolean values, the Available Data only has a minimal increase from 7.5 to 7.6 as shown in Graph 2. However, Test 2 Artefact 2 shows to be more effective for improving performance for 4 stakeholders out of 7 as shown in Graph 1 wherein 4 stakeholders have right of the graph line Acceptable values. This is an improvement as compared to Artefact 1 with only 1 Acceptable and Test 1 with only 2 Acceptable values. Test 2 Artefact 1 also shows to have resulted in a greater increased Data Value from 35% to 58% as shown in Graph 2.

### 5.2.4.2 Experiment 2

Artefact 2 is a visualisation on plan view without a map underlay and appears to contain more technical annotations. This was also used in the urban design development involving a micromobility infrastructure project. As shown in Graph 1, Artefact 2 is rated as Inappropriate for all stakeholders except for building owner stakeholder. This is indicated by the left of the graph line Inappropriate values for all except the building owner stakeholder. Graph 2 also shows Artefact 2 to contain 9.8 Available Data, 65% of which is considered as Data Failure, which is a portion of Artefact 2 that does not meet stakeholders' requirements.

Test 1 Artefact 2 modulates the score to match urban designer stakeholder Boolean values. It shows that this resulted in improving performance for all stakeholders except for building owner stakeholder, which has worsened as indicated by the greater left of the graph line Inappropriate value. But generally, it shows in Graph 2 that Test 1 Artefact 2 has greatly increased its Data Value from 35% to 62%, albeit with a greatly increased Available Data from 9.8 to 18.6.



**Figure 5.5:** Test 2 Artefact 2 added path data shown with arrows which increased Acceptable values of 4 out of 7 stakeholders.

Test 2 Artefact 2 modulates the score to match micromobility device user stakeholder Boolean values. Experiment 2 shows that Test 2 is more effective at improving performance for 4 stakeholders out of 7 as shown in Graph 1 wherein 4 stakeholders have right of the graph line Acceptable values, an improvement from Artefact 2 with only 1 Acceptable right of the graph line value. Interestingly though, Test 2 Artefact 2 the Available Data is a decrease from Artefact 2 of 9.8 to 8.6 as shown in Graph 2, which means it has less graphical information. Although it is a decrease in Available Data, its performance is most improved showing an increase of nearly double Artefact 2's Data Value from 35% to 69%.

#### **5.2.4.3 Experiment 3**

Artefact 3 differs in that it features an elevation view compared to Artefacts 1, 2 and 4 which feature plan views. Artefact 3 is also a visualisation used in the urban design development involving a micromobility infrastructure project. As shown in Graph 1, Artefact 3 is rated as Acceptable to 4 out of 7 stakeholders indicated by 4 right of the graph line values, which means it rated as better performing generally as compared to Artefacts 1, 2 and 4 which have less right of the graph line values. It also shows in Graph 2 that Artefact 3 has a better performance score as it has a higher Data Value at 49% compared to Artefacts 1, 2 and 4 that have greater portions of Data Failure. Albeit, Artefact 3 has one of the lowest Available Data at 8.3.

Test 1 Artefact 3 represents an enhanced iteration of Artefact 3, designed to benefit the urban designer stakeholder. Overall, this improvement had a positive impact on all stakeholders, except for the building owner stakeholder, on which the artefact's performance value, indicated in Graph 1, displayed a greater "Inappropriate" rating compared to the previous artefact. While Test 1 demonstrates an increase in Available Data from 8.3 to 10.7, as shown

in Graph 2, the Data Value rate of change only marginally improved from 49% to 51%. This suggests that the type of added data is not too effective in bringing about a greater result improvement.

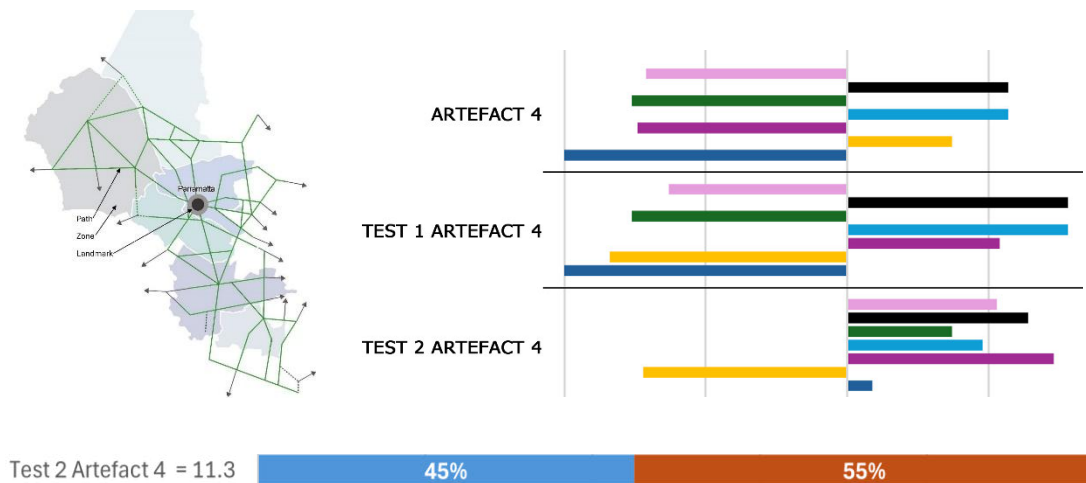
Test 2 Artefact 3 also represents an enhanced iteration of Artefact 3 to match the micromobility device user stakeholder Boolean values. In a similar trajectory compared to Experiments 1 and 2, this version is improved from the previous iterations of Test 1 and from the original Artefact 3. This is apparent in Graph 2 showing a jump of Data Value from 49% to 77%. It also shows as the best performing artefact indicated by its amount of the least Data Failure at 23% compared to the other samples. Although this is the case, in Graph 1 it shows that it is only Acceptable to 4 out of 7 stakeholders, a similar outcome to Test 2 in both Experiments 1 and 2, with 4 Acceptable values and 3 Inappropriate values.

#### **5.2.4.4 Experiment 4**

Artefact 4 is a visualisation on plan view of a large geographic scale. This has a map underlay similar to Artefact 1, but it differs in scale to Artefact 1 and 2 as it features a larger geographic area. Artefact 4 was also used in the urban design development involving a micromobility infrastructure project. In Graph 1 it can be observed that Artefact 4 rated as Acceptable to 3 out of 7 stakeholders. In terms of rating, this has a better performance result compared to Artefacts 1 and 2 in Experiments 1 and 2 which shows only 1 Acceptable rating out of 7. Interestingly however as shown in Graph 2, Artefact 4 has the lowest Data Value scoring at 33% compared to all samples. Albeit, it has the highest Available Data at 13.2 compared to Artefacts 1, 2 and 3.

Test 1 Artefact 4 is an altered version of Artefact 4 to match urban designer stakeholder requirement Boolean values. As shown in Graph 1, Test 1 has resulted in a slight improvement

for four stakeholders, city planner, urban designer, engineer and pedestrian, and a change for micromobility device user from Inappropriate to Acceptable. However, Test 1 resulted in performance decline for motor vehicle driver from Acceptable to Inappropriate and produced the same Inappropriate value for building owner.



**Figure 5.6:** Test 2 Artefact 4 increased Acceptable to 6 out of 7 stakeholders due to added zone data as map underlay, but has 55% Data Failure

Test 2 Artefact 4 is depicted in Graph 1 as having the highest number of Acceptable ratings at 6 out of 7 stakeholders compared to the other evaluation samples. However, despite this favourable assessment, its Data Failure rate is at 55%, as illustrated in Graph 2. This inconsistency can be explained by noting that while Graph 1 indicates that Test 2 is Acceptable to 6 stakeholders, the associated values hover around the 50th percentile of acceptability. Thus, the artefact's effectiveness in stakeholder communication remains limited, despite its Acceptability rating.

## **5.2.5 RESULT FROM SHAPE, LABEL & WEIGHT PERFORMANCE**

Tests 1 and 2 across the four experiments represent iterations of the visual data in the original artefacts. These tests illustrate how artefacts can be manipulated through variations in visual data, the types of shapes, such as points, lines, and planes, as well as their frequency within the artefact. These manipulations significantly influence visual representation, either enhancing the layer of meaning conveyed or potentially limiting it. This highlights the critical role that shape selection and arrangement play in improving an artefact's effectiveness.

For instance, Test 2 Artefact 1, as illustrated in Graph 2, exhibits the second lowest Available Data at 7.6, which reflects the calculated contributions of shapes and graphical attributes, including labels and weights. Test 2 features a limited number of lines and planes used to depict urban elements such as path, edge, zone, and node. Importantly, Test 2 does not require the representation of edges; consequently, the modifications involved the removal of lines and planes representing edges. This change enhanced its performance, when compared to Test 1 and Artefact 1. Data Value increased as shown in Graph 2. By eliminating the representation of edges, the artefact avoids penalties associated with non-compliance, thereby aligning with the specified requirement for Test 2. This strategic manipulation of the use of shapes illustrates a graphical intervention to improve an artefact's performance score and rating, resulting in optimising the effectiveness of Test 2.

As well in Test 2 Artefact 1, the graphical information attribute of label is exemplified through the use of arrows to indicate direction. This incorporation of arrows transforms the line shape, aligning line and arrows with the representation of the urban element of path, which serves as a route or channel for movement. The arrows effectively denote directions, to communicate that movement is intended along the line shape which serves as path. Consequently, the inclusion of labels in this context enables the conveyance of the urban

element of path, thereby increasing the Data Value, as illustrated in Graph 2. This highlights the importance of labels in enriching the use of shapes.

The impact of the graphical information attribute of weight is also evident in Test 2 Artefact 1. Specifically, the use of colour on the line shapes introduces an additional layer of meaning, with different colours signifying distinct purposes. For instance, the red line clearly indicates the path designated for motor vehicles, while the pink lines represent pedestrian pathways. This effective use of colour enhances understanding. It also contributed to improving the artefact's scoring and increased Data Value.

#### **5.2.6 IMPACT OF CALIBRATION PROCESS ON RESULTS**

The use of Calibration tables enables the system to be adjusted to accommodate various conditions for analysis and evaluation. The impact of the use of calibration tables are discussed:

##### **CALIBRATION TABLE 1**

Calibration Table 1 establishes the parameters of the system in relation to stakeholders' requirements, serving as a crucial mechanism to connect project stakeholders with urban elements such as path, edge, zone, node, landmark, and district. This table enables the systematic mapping and cross-referencing of stakeholders with urban elements using Boolean values to identify their associations.

A significant aspect of this calibration table is that it requires domain knowledge. The associations drawn between stakeholders and urban elements are largely based on assumptions rooted in industry experience and expertise. For example, as illustrated in Table ## of Sub-Section 3.3.3.1, the city planner stakeholder is identified as requiring path, zone, and district. This assumption arises from the understanding that city planners may prioritise these elements over edge, node, and landmark. Edges, for instance, are linear features that delineate between

different areas and serve as lateral references, which are primarily associated with design and function. Similarly, nodes are often related to strategic foci, acting as active junctions or points where paths converge. Landmark, an urban element that is characterised by its distinctive features that set it apart from their surroundings, which are also considered to be less of a priority to city planners. As such, edge, node and landmark receive a designation of '0' or No/False in their association with city planners.

Consequently, this cross-referencing process inherently contains an element of subjectivity, as interpretations of these associations can vary slightly from different viewpoints. However, the impact of this calibration can significantly influence the results of the evaluation. The matrix established in Calibration Table 1 serves as the foundation for assigning and calculating penalties, thereby impacting the scoring and the rating in the evaluation process. A slight change in the matrix can produce different results, for instance, instead of Acceptable, it can be rated as Inappropriate.

## CALIBRATION TABLE 2

Similarly, Calibration Table 2 establishes critical parameters within the system, functioning as a mechanism to categorise the graphical representations of objects that populate artefacts used to depict urban scenes. This categorisation aids in articulating design ideas effectively. As this research recognises that urban design is comprised of urban elements of path, edge, zone, node, landmark, and district, consequently, the graphical objects represented in the artefact are classified under one or more of these elements.

Calibration Table 2 presents a tabulated list of urban objects which is mapped and cross-referenced with the urban elements using Boolean values to identify their associations. Similar to Calibration Table 1, a crucial aspect of this process is the requirement for domain knowledge,

as the associations are based on assumptions derived from industry experience and expertise. Identifying and categorising these objects into the appropriate urban elements can be complex.

For instance, the experiments presented in the research focuses on communication artefacts related to the design of micromobility infrastructure within an urban context. Thus, many of the graphical objects in the artefacts depict common elements found in street scenes, such as roads, buildings, and pedestrian sidewalks. In Experiment 2, for example, Artefact 2 includes portions of buildings that interface with pedestrian sidewalks. In this context, the buildings are categorised as edges, as their subject matter relates directly to the pedestrian space and as the buildings delineate where the pedestrian area ends. Conversely, buildings may be classified as landmarks when the focus is on urban form or as zones when discussing land use. These examples underscore the necessity of domain knowledge in this categorisation process. As well, the impact of this classification process can significantly alter the outcomes of the evaluations, as the urban elements of path, edge, zone, node, landmark, and district interconnect with Calibration Table 1. This intricate relationship emphasises the importance of accurate categorisation of urban objects.

### CALIBRATION TABLE 3

Calibration Table 3 serves the computation component for the system's statistical analysis and establishes critical parameters relating to value calculation. It identifies fundamental parts of the formula, encompassing shape, label, and weight, while categorising the graphical dimensions associated with each element from 0 to 3. As discussed in previous chapters, the graphical dimensions include point, line, plane, and solid. In Calibration Table 3, each graphical data element related to shape, label, and weight is assigned a percentage value, collectively summing to 100%, as they represent parts of a whole.

Similar to Calibration Tables 1 and 2, the process of allocating these percentage values requires user input, introducing a degree of subjectivity. Throughout the four experiments, the values were consistent and defined at 50% for shape, 25% for label, and 25% for weight. This allocation signifies that shapes, such as points, lines, and planes, are considered more valuable than labels, which include symbols and text, and weights, which encompass attributes like colour, hatching, and line types. Consequently, imagery featuring more defined shapes yielded a higher value compared to that with less defined shapes.

However, in scenarios where photorealistic representations are deemed more desirable, the system user can allocate a higher percentage value to weight. Thus, in this scenario, photorealistic or artistic imagery with less defined shapes could achieve a greater overall value than technical drawings with more pronounced shapes. Ultimately, Calibration Table 3 grants users the flexibility to define the conditions under which the artefact will be analysed, allowing for a tailored approach to evaluation of artefacts.

#### **5.2.6.1 Stakeholder vs Urban Element Boolean Mapping Calibration**

Stakeholder Requirements is a system variable and is replaceable. The process associated with Calibration Table 1 presents a complex and nuanced challenge. While one could argue that all urban design elements are significant to every stakeholder, the task lies in filtering those that are most pertinent and relevant for each individual stakeholder. This task therefore is primarily based on an understanding of each stakeholder's role and expertise.

In reviewing the list of stakeholders, the research clearly delineates two distinct groups: domain experts, which include city planners, urban designers, and engineers, and non-domain experts, comprising the general public. Usually, a general artefact is developed to cater to all within the non-domain experts' group. As in practical application, it is uncommon to further

differentiate subgroups within the non-domain experts for the purpose of developing artefacts that address their diverse needs.

Although the experiments revealed that stakeholders within the same group possess different requirements, the mapped needs were largely based on general assumptions, which can raise potential concerns about the validity of the process. For example, the building owner stakeholder was assigned zone and landmark, reflecting an assumption that these issues are paramount for the building owner stakeholder concerned with land use and building form. However, this perspective can be viewed as overly simplistic.

Conversely, one might argue that a city planner stakeholder would be concerned with all urban elements, complicating the identification of their top priorities. Yet, it can be reasoned that city planners may place less emphasis on edge compared to engineers. Therefore, using this logic, this is reflected in the experiments, where city planners are allocated a '0' for edge. Thus, the meticulous mapping of these parameters is crucial from the outset and as the list of stakeholders can be adjusted to decrease or increase.

#### **5.2.6.2 Urban Object vs Urban Element (theory) Boolean Mapping Calibration**

The theoretical description for urban space, articulated through the concepts of path, edge, node, landmark, and district in Kevin Lynch's seminal work, "The Image of the City," provided a foundational basis for categorising the assorted graphical representations of urban objects found in the artefacts used in this research. This helped in formalising the basis on which the artefacts are being evaluated to communicate urban design, as this framework is a vital benchmark that is widely recognised to provide the visual formula for urban form.

As discussed in Calibration Table 2, the process of identifying urban objects and categorising them into the appropriate urban elements can be complex. The original list of

urban elements was derived from Lynch's empirical methodology that aimed to capture the physical components that shape a city's image. However, during the review process of the artefacts, it became apparent that this list lacked a critical element capable of conveying areas with specific significance—similar to having the concept of “zone.” Zones can represent voids in urban form, encompassing spaces that lack a defined shape, such as open areas, water bodies, and informal gathering spots which may not fit neatly into the categories of path, edge, node, landmark, or district, yet they are essential for a comprehensive understanding and for conveying urban design.

To address this gap, the research proposed the addition of "zone" as an urban element. This adjustment proved valuable in enhancing the communication of urban design, particularly in Experiment 1, where Artefact 1 focused on integrating walking and cycling infrastructure. Therefore, communicating information about pedestrian pathways was critical and it was insufficient to merely indicate the existence of a pedestrian footpath. Understanding how the footpath can accommodate bi-directional movement was essential. Consequently, Tests 1 and 2 in Experiment 1 explicitly illustrated walking zones, effectively capturing the nuanced pedestrian traffic on the footpath.

This adjustment to the list of urban elements was beneficial in aligning the mapping of urban objects. The addition of zone provided a more comprehensive definition to represent nuance in urban design artefacts.

### **5.2.6.3 Shape, Label & Weight Percentile Assignment Calibration**

As explored in the literature review, Stiny posits that “it's the need to count—to measure information—that makes bits important.” He rationalised designs by dividing them up into components that can be manufactured and assembled. It was proposed as a way to calculate

designs and measure information using components that are made up of constituent parts, or units to allow calculations to be done. This provided the basis for quantifying visual data and calculating information contained in artefacts by using Stiny's shape, label and weight algebra.

The review of the artefacts in the experiments showed a variety of aesthetics was used to visualise and communicate design intents. For instance, Artefact 2 employed extensive linework, which emphasises the technical features of the design, while Artefact 1, characterised by map imagery and colour schemes with minimal linework, conveyed the spatial qualities of the design in a less technical style. This contrast illustrates the delicate balance between defined details expressed through precise line drawings and the more evocative graphical elements that provide additional depth and qualities of urban design. This balance is a critical consideration in communication throughout the various phases of the project and is closely tied to the intended purpose of each artefact.

To accommodate the variety of aesthetics across the artefacts, the evaluation system introduced a value percentile framework, which can be adjusted according to Calibration Table 3. Although assigning percentile values for shape and the graphical attributes of label and weight can be onerous, the value distribution is a critical parameter that offers flexibility within the evaluation system. The process of assigning values however requires a level of domain knowledge related to visual graphics, as understanding the nuanced impacts of shapes—such as points, lines/curves, planes, and solids, as well as the graphical attributes of labels and weights—is not easily acquired.

For instance, if the goal is to achieve a textured visualisation that evokes the atmospheric qualities of space, then the graphical information attributes of weight might warrant a higher value than shape or linework. An example of this value distribution could be 30% for shape, 20% for label, and 50% for weight. Such a distribution would significantly influence the overall

results, as the use of weight graphics—including shading, hatching, and colour—would attract a higher calculated data value.

Moreover, assigning the 50% value allocated to weight requires further distribution of the value across the dimensional data of points, lines, planes, and solids. The impact of this will further refine the desired type of textured visualisation. For example, if conveying nuance through shading for additional depth is prioritised, a higher percentage can be allocated to planes, resulting in increased data value when employing extensive hatching and colour schemes. For example, a potential distribution could be 10% for points, 10% for lines/curves, and 30% for planes.

Conversely, if the emphasis is on clear, defined linework over atmospheric qualities, a higher value could be assigned to lines/curves, leading to improved data value when more defined, coloured and various line types for line/curve are featured.

Ultimately, measuring information in urban design artefacts involves quantifying data units, as Stiny suggests. However, in the quest to understand and align data impact, the intricate process of assigning values to statistical data can refine the lens through which the artefacts are evaluated.

#### **5.2.6.4 Penalty Application for Evaluating the Data Value and Impact on Results**

The application of penalty calculation involves taking the data values established during the initial phase of analysis and relies on the cross-referencing of urban elements with stakeholder requirements, as defined in Calibration Table 1, to deduct penalties from the data values for data non-compliance. In the experiments, penalties were imposed under two conditions: first, when an urban element is absent despite being required, and second, when an urban element is available but not required. In the experiments, under both conditions the

artefact incurred a uniform penalty of -1 for all element non-compliance. However, a careful review of the experiment results suggests that the penalty system may benefit from further refinement.

In consideration for ‘value in information’, it becomes evident that the amount of penalty for both conditions requires scrutiny, as it is reasonable to consider that the absence of a required element should carry a more severe penalty than the presence of an unnecessary one. Therefore, it can be proposed that the first condition carry a higher penalty than the second condition. Although this adjustment will significantly alter the evaluation outcomes, it can ensure that an artefact with a higher data value, even if penalised, retains greater worth compared to an artefact that lacks essential data.

With this adjustment, the penalty system can be used to more accurately reflect the artefact’s value, allowing for a nuanced distinction between the importance of data presence and absence, and further improving the evaluation process.

### **5.3 FINDINGS ON THEORY, TOOLS & PRACTICES**

#### **5.3.1 FINDINGS FROM IMPLEMENTING THE ALGORITHMIC AESTHETICS THEORY**

##### ***Algorithmic Aesthetics Rigor with Flexibility, yet Laborious***

Aesthetics in this theory is concerned with ‘the philosophy of criticism and design. Algorithmic Aesthetics is an investigation of aesthetics in terms of algorithms’ (Stiny & Gips, 1978). It formalises a system for how a piece of work can be understood and how to evaluate its quality, thereby postulating a structure for the algorithm components in a system. The components fix the main aesthetic concepts of description, interpretation, and evaluation, with each given a precise definition. Implementing the proposed Algorithmic Aesthetics system to

analyse and evaluate urban design communication artefacts pins down ambiguous graphical concepts in artefacts. How graphical schemes in artefacts can be interpreted in terms of their use to convey design and how the qualities of these schemes can be described were formalised in this process.

### **5.3.1.1 Phase 1 and Phase 2 Implementation**

The benefit of the Algorithmic Aesthetics schema is that the components of the algorithms which are considered as black boxes with their own internal workings can be used to store the critical graphical and urban design concepts introduced in this research that were used to interpret, describe and evaluate the artefact. The system listed 7 main components which included 1. Object, 2. Receptor, 3. Description of Object, 4. Graphical System, 5. Analysis Algorithm, 6. Description Interpretation and Evaluation, and 7. Effector. The Object in this case is the artefact to be analysed and evaluated. This format was implemented for both phase 1 artefact analysis and phase 2 artefact evaluation.

In phase 1, the Receptor was initially tricky to identify, but it can be reasoned that the way the urban design is recognised is through the use of the graphical objects in the artefacts. Therefore, urban objects such as those visually represented by the graphical elements and organised in the scene such as the roads, trees, footpaths and the like, featured in the artefact are considered the Receptor. The Receptor items or urban objects then needed to be identified in the system, and which tie in with the third component of Description of Object. The Description of Object in this case introduced the use of Lynch's urban elements of path, edge, node, landmark and district. That urban design can be described in these terms is a well-known theory in urban design which served to ground and validate the evaluation process. The fourth component of Graphical System provided an opportunity to introduce the use of Algebra of Shapes. This proceeds to the fifth component of Analysis Algorithm, during which based on the Algebra of Shapes allowed the graphics of urban elements and urban objects to be

quantified in a logical way that is grounded in visual grammar theory. Thus, data visibility and data count described in the system enable the statistical analysis of urban design. The sixth component of Description Interpretation and Evaluation is about the introduction of a strategy to interpret the statistical analysis into meaningful data by allocating a percentage value to the collected data, as per Calibration Table 3. The seventh component of Effector is the result of the computation that produces the data values for each element contained in the urban design artefact.

This result becomes the Object input for phase 2 artefact evaluation, which has the same black box system format used in phase 2. The second component Receptor for phase 2 is the list of stakeholders. This leads to the third component of Description of Object which aligns with the use of a matrix for stakeholders and urban elements. The fourth component in phase 2 of Aesthetic System is the process of cross-referencing stakeholders and urban elements as per Calibration Table 1. The fifth component in phase 2 of Analysis Algorithm is the introduction of the penalty calculation to penalise non-compliance and refine the evaluation of artefacts. The sixth component in phase 2 of Description Interpretation and Evaluation is the process of exacting the Required Element Data for each stakeholder and calibrating as required. The seventh component in phase 2 of Effector is the resulting score and rating evaluation of the artefact.

### **5.3.1.2 System Challenges & Evaluation**

In phase 1, the Receptor and Description of Object are based on the ability to ‘see’ the urban objects and associate these with the urban elements of design used as the grounding theory. Although it formalises the urban objects into meaningful categorisation, this process can be onerous and susceptible to human error, and as well can be open to interpretation.

As previously discussed, in Artefact 2 the part of the building featured in the artefact was classified as an edge element. However, this classification is not without ambiguity, as the building object can also be categorised as landmark, district, or even zone in certain contexts. This ambiguity highlights a potential weakness within the proposed Algorithmic Aesthetics schema. In contrast, other components of the schema exhibit greater durability, as they effectively can accommodate variability and adapt to changes in conditions. To summarise, one key strength of the system is its ability to fine-tune visual data calculations and percentage value distributions across shape, label and weight, to reflect diverse analytical perspectives and conditions. Furthermore, the graphical data, encompassing shape, label, and weight, and their dimensional derivatives are distinctly defined, making them less susceptible to varied interpretations. This was evident in the different artefacts utilised. For example, the artefacts varied in scale. Artefacts 1, 2, and 3 represent smaller urban design scales, while Artefact 4 features a larger regional scale. Similarly, it was evident in the varied artefact views, including the plan views of Artefacts 1, 2 and 4, alongside the elevation view of Artefact 3. The use of shape, label and weight was equally applicable across these variations.

Another key strength of the system lies in its capacity to refine statistical analysis by eliminating redundancies. This was achieved by deactivating non-relevant urban elements in Calibration Tables 1 and 2, thereby mitigating potential biases in analysis and evaluation. For instance, in Experiments 1, 2, and 3, the urban elements of landmark and district were disabled, as these artefacts focused exclusively on smaller city areas, rendering landmark and district irrelevant for the calculations. Likewise, in Experiment 4, the edge element was disabled, as it was unlikely that the artefacts under investigation could effectively convey the element of edge. Consequently, edge was excluded from the overall calculation. This approach of disabling irrelevant elements helped to further enhance the accuracy and reliability of the system.

The integration of phase 1 and phase 2 within the Aesthetic Algorithm schema demonstrates its versatility, as both phases are able to utilise the same consistent format of the system. However, a notable weakness arises in the process of mapping stakeholders to urban elements. While this mapping formalises parameters for relevant data and establishes a benchmark for evaluating artefacts, it is susceptible to human error and ambiguity. The research concedes that this method lacks scientific grounding, rendering it a subjective process. Until a more objective approach is developed, this mapping remains critical for formalising stakeholder requirements within the evaluation system. In contrast, components of the evaluation system that exhibit greater durability included the assignment of penalties, the calibration mechanism, and the scoring and rating methods. These components are responsive to variability and can effectively accommodate diverse viewpoints and adapt to changing conditions. This allowed for the fine-tuning to achieve quality benchmarks as discussed previously.

Overall, the implementation of Algorithmic Aesthetics theory provided a coherent framework for the research. It facilitated a more structured way to coordinate urban design concepts and visual grammar. This significantly enhanced data organisation and supported the sequential process of analysis. The use of the Algorithmic Aesthetics also defined a system that can comprise various interconnected components that can be isolated for future review, and adjusted, or redefined without compromising the integrity of the overall structure.

### **5.3.1.3 Challenges on Application of Theory: Data Mapping**

Although this proved a viable framework, it was not without challenges. Implementing this theory for the research was not straightforward. Mapping an analysis framework for was unclear and did not come with instructions as to how the framework can be practically applied for this research.

Overall, the application of Algorithmic Aesthetics theory emerged as a viable framework. The flexibility afforded by the black box system facilitated the development of the system mechanics, which were tailored to the specific activities necessary for the analysis and evaluation process. Ultimately, this framework allowed for a more systematic, adaptable and objective approach to evaluating urban design artefacts.

### **5.3.2 FINDINGS FROM USING TOOLS IN THE EXPERIMENT: MAINSTREAM YET VERSATILE AUTOMATION**

The research employed various software tools throughout the experiments. The statistical analysis of the original four artefacts, and the development of Test 1 and Test 2 artefact versions for all four experiments were conducted using Grasshopper and Rhino software. Additionally, the computational analysis and evaluation system, and accompanying graphs and charts were created in Excel. Grasshopper, a visual programming language that operates within the Rhinoceros 3D CAD application, provided numerous advantages during the experiments. This approach facilitated a more efficient generation of the geometric figures used for the statistical analysis of artefacts across Experiments 1 to 4 and produced faster iterations. The visual programming capabilities of Grasshopper enabled a parametric workflow, allowing for dynamic adjustments to increase or decrease the graphical elements used in Tests 1 and 2 through mathematical formulas.

For the development of the statistical data analysis and evaluation, the use of Excel software offered benefits in the production testing stages. The system is highly computational; hence it required an application that can organise data, accommodate efficient data analysis and be able to produce effective data visualisation of charts and graphs. Excel has built in formulas and functions that were highly beneficial in developing the value calculations,

allocating and developing the computation for value distributions as well as developing the penalty calculations. This also enabled the dynamic testing of conditions during the experiments.

The organisation of data, formulation of equations, and development of calibration mechanisms were efficiently achieved using Excel spreadsheets. The automation of calculations and results was enabled in Excel, allowing any modifications within the system to be automatically reflected. This also enabled rigorous testing of the calibration tables and streamlined calculations and automated the final ranking and scoring results. Moreover, the data visualisation using charts and graphs were easy to produce. The integration of these software tools enhanced the efficiency of the experimentation process. However, the use of Excel primarily served to illustrate how the system can be constructed and showed how the Algorithmic Aesthetics framework can be developed and can operate with dynamic calibration tables. This approach is by no means advanced; rather, its rudimentary application represents a foundational exploration of the Algorithmic Aesthetics system for artefact evaluation. For instance, input parameters and adjustments to the calibration tables were performed manually. Such a system would greatly benefit from sophisticated interfaces and advanced data processing that can enable real-time interaction and visualisation.

### **5.3.3 FINDINGS FROM USING THE CASE THEORY**

Lynch's theory is an Input Variable that can be changed. The experiment showed Lynch's theory as a valuable framework for scrutinising and interpreting urban design artefacts rationally, and an applicable method for image analysis. The urban elements of path, edge, node, landmark and district provided a basis for classifying the graphical contents found in artefacts. The contents which are generally depictions of items found in an urban setting are

found to have relationships with Lynch's urban elements. The items which are called in this research as urban objects, serve to create the composition that conceives the urban elements' imagery. For instance, a motor vehicle object conveys the image of a road path, and a building object can convey the image of an edge, or landmark or district. This became a way to rationalise the graphical data contained in artefacts. However, whilst examining the artefacts, it became evident that there is a gap in this application.

To effectively convey urban design intent, it was evident that critical design concepts needed to be articulated to reflect how spaces can be identified and function within the urban environment. However, the notion of "space" does not align neatly with Lynch's established list of urban elements, making classification of objects relating to space challenging. Consequently, this research introduced "zone" as an additional urban element, allowing for a more nuanced classification of urban objects related to spaces with specific functions. For instance, street furniture located along a pedestrian footpath can signify a zone dedicated to outdoor dining. Zones are defined as specific areas dedicated for specific functions and are neither paths nor nodes. For instance, open space in urban design can appropriately be classified as zone.

In the Algorithmic Aesthetic Systems, Lynch's elements can address large-scale urban environments (experiment 4), as well as smaller portions of the city (experiment 1, 2, 3), serving as visual anchors that connect to the broader urban context. For the first system testing, the use of Lynch's terminology is mainly for flexibility. It is flexible in terms of scale. An Edge can mean the river in a wider city plan or a kerb in a street plan. Likewise, a landmark can mean a great tree in a square or the square in a town. Applying this to environments of different scales was then tested in this research. It was reasonable to assume that one or more of Lynch's key elements will feature as a critical detail in visual communication artefacts. Evidently, the artefacts conveyed urban design using Lynch's elements to reflect scenes characterising parts

of the city. Thus, as a Description of Object for the Aesthetic Algorithm schema in Phase 1, as an Input Variable, Lynch's theory provided a logical terminological approach for analysing urban design artefacts, using urban elements to deconstruct and quantify visual information.

#### **5.3.4 FINDINGS FROM CHOOSING THE CASE STUDIES AND PRACTICES**

Finding #1: The multiple scale of case studies allows for comparison of how the same shape can be analysed in different context and stakeholders

While these urban design projects incorporated cycleways, the selected artefacts were varied in many ways to evaluate the system's capabilities effectively. Artefacts 1 and 4 utilise map underlays which serve to enhance visualisation, whilst employing less graphical data related to shape, label, and weight to convey design intent. In contrast, Artefact 2 shows a greater amount of graphical data and features more technical details. Artefact 3 features an elevation view, a contrast from the plan views featured in the other artefacts. Lastly, Artefact 4 features a large geographic area, whilst the other artefacts focus on smaller-scale designs with specific urban contexts. This variation in artefact characteristics allowed the initial exploration and assessment of the system's effectiveness across a variety of visual design representations.

Finding#2: Each case study provides an adequate level of complexity where layers of shape, labels, and weights, can be queried into multiple combinations, each can be tested and counted in the system.

## **5.4 RESULT VS HYPOTHESIS**

### **5.4.1 RESEARCH HYPOTHESIS**

The research hypothesised that visualisations in urban design that align with stakeholder needs improve the communicative value of artefacts.

#### **1. urban design artefact's information can be analysed and measured**

The Algorithmic Aesthetic schema developed in this research demonstrated that the information contained in artefacts can be systematically decomposed into measurable data. This was evident through the process of quantification and the logical measurement of the artefact's visual graphic content. The statistical data analysis conducted in Phase 1 of the schema effectively decomposed the visual contents that enabled data to be quantified and recognised as Available Data and Valuable Data. This is also evident in the use of Calibration Table 3 that assigns values to graphical content and discussed in Sub-Section 5.2.3.3 Shape, Label & Weight Percentile Assignment Calibration. This experiment was carried out using artefacts described in Sub-Section 5.3.4 Findings from Choosing the Case Studies and Practices. The experiments evaluated 2D urban design artefacts with diverse features relating to scale, graphic style and views, which demonstrated the system's capabilities.

To This extent, the system demonstrated a process that identifies urban design information being communicated, and a process that measures the level of information being communicated. This is evidenced by the Data Value assigned to each urban design element contained in the artefact. As a result, the research through statistical data analysis proved that 2D visual artefact communication in urban design can be quantified and measured, thereby addressing the first hypothesis requirement of the research. In the same token, the research has not proven that 3D urban design artefacts can be quantified and measured in the same way.

This is not part of the scope of the research. This reveals an obvious next step for future research.

**2. visual communicative performance can be measured and correlated to stakeholder requirement conditions.**

The second hypothesis requirement, which is to demonstrate how communicative performance can be measured and correlated to stakeholder requirement conditions, is addressed in two-fold. The first part is the development of a method to correlate stakeholder requirement conditions which is discussed in Sub-Section 5.2.1 Stakeholder vs Stakeholder Relevancy. The second part is the development of a method to measure artefact performance which is discussed in Sub-Section 5.2.3 Impact of Calibration Process on Results. This second hypothesis requirement directly relates to phase 2 of the Algorithmic Aesthetic schema which is focused on evaluating the artefact's data values quantified in phase 1, against stakeholder requirements.

The part 1 correlating data values with stakeholder requirements was demonstrated by implementing the penalty computation discussed in Sub-Section 5.2.3.4 Penalty Application for Evaluating Data Value and Impact on Results. The penalty allocation worked in concert with Calibration Table 1 which dictated stakeholder requirements and discussed in Sub-Section 5.2.3.1 Stakeholder vs Urban Element Boolean Mapping Calibration. The use of the penalty system constrained values to relevant data and penalised for non-compliance to more accurately the artefact's fitness in complying with stakeholder requirements. In tandem, the use of the Boolean mapping of stakeholder requirements demonstrated how the data contained in artefacts can be cross-referenced for relevancy against a set of prescribed requirements. The calibration table essentially defined which urban design data from a list of prescribed urban elements in the Kevin Lynch case theory are relevant to stakeholders. However, as discussed in Sub-Section 5.2.3.1 that although the experiments demonstrated the capacity of the system

to cross-reference prescribed stakeholder requirements, the experiments based the requirements largely from general assumptions that the author gained through experience in the industry, and from understanding of each stakeholder's role and expertise.

As a result, the research was able to prove that artefact information can be precisely correlated with stakeholder requirement conditions and measured for data fitness. However, the research does not prove that stakeholder requirements were drawn from scientific basis. This point is beyond the scope of the research. Hence, the tabling of requirements set out in Calibration table 1 can benefit from a more sophisticated process for identifying requirements. This point as well provides a next step for future research.

Part 2 which involves the development of a method to measure artefact performance was evidenced by the system's capability to produce a performance result that reflected a rating of Acceptable or Inappropriate, and a score of the percentage of data that is deemed valuable to the stakeholder. The computation developed in the system calculated the fitness of the data by applying penalties against data values. The remaining total sum of data values were calculated to produce a score that reflected the percentage of data contained in the artefact that is considered valuable to individual stakeholders. This is discussed in Sub-Section 5.2.1 Result from Artefact vs Stakeholder Relevancy. As a result, the research demonstrated that a method for measuring artefact performance can be effectively developed. To address the second hypothesis requirement, Parts 1 and 2 proved that communicative performance can be quantitatively assessed and correlated with stakeholder requirements. These findings elucidate the extent to which the hypothesis has been proven, providing a clear delineation of what has been validated and what remains unproven.

## **5.5 SUMMARY**

The experiments produced a score and rated each of the four selected artefacts, providing a score that indicated the percentage of data that has value and is relevant to each stakeholder. The ratings further assessed whether each artefact was deemed acceptable or inappropriate based on stakeholder criteria.

The findings summarised significant aspects of the research in relation to the theories used in the experiments, the tools employed to carry out the experiments, the suitability of the case theory of Kevin Lynch, and the case studies and artefacts selected. The use of the Algorithmic Aesthetics theory has some challenges in terms of implementing the system. The tools highlighted the use of available mainstream software to develop the system prototype. Although it was basic, it worked sufficiently to demonstrate the workflow and apply computational processes. The research added ‘zone’ to the list of Kevin Lynch’s urban elements. The selected artefacts and case studies offered sufficient variability with 2D artefacts however lacked the 3D sample for testing the system. Finally, the key points were presented to demonstrate how the hypothesis was validated.

### **5.5.1 EXPERIMENT LIMITATIONS**

The experiments presented several limitations as discussed throughout this chapter. Firstly, the system was developed using basic tools for initial exploration, which limited the functionality of certain components. Specifically, 1) the manual review of artefacts relied on the detection and recognition of urban objects by human operators. 2) the collecting and recording of statistical data extracted from the review of the artefacts required manual input. 3) the process required the manual mapping of urban objects to urban elements. 4) there was a lack of a scientific basis for identifying stakeholders’ requirements. 5) the case studies also restricted the experiments to 2D urban design artefacts, limiting the exploration into 3D

artefacts. Notably, another significant limitation was the system's inability to automate the production of an optimal artefact that could precisely meet the diverse requirements of each stakeholder. As such, the basis for developing the Assumptions is outside the scope of my thesis. These were formulated to demonstrate how the system is structured and how they can impact the evaluation results. Because of these fragilities my system may only work for certain group of stakeholders and projects. Assumptions from one project may not suit other projects. So that the system is designed with calibration features as Assumptions in the system is not prescriptive. But in this limited scope, the system is able to demonstrate its capability. As well, the experiments were limited to theoretical testing. Real-world application is unproven.

### **5.5.2 EXPERIMENT BENEFITS**

The experiment investigated previously untested theories regarding visual urban design communication. It demonstrated a robust system using statistical data analysis grounded in the visual theory of the Algebra of Shapes and graphical information attributes to evaluate visual urban design artefacts. Additionally, the experiment demonstrated the use of a computational system made up of a network of components, each functioning as a discrete unit that can be calibrated or replaced without compromising the integrity of the overall system. Furthermore, to a greater extent, the experiment proved the research hypothesis, that visualisations in urban design that align with stakeholder needs improve the communicative value of artefacts.

# Chapter 6: Conclusion

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## 6.1 CONCLUSION

This research set out to evaluate the communicative efficacy of visual communication artefacts in urban design—such as drawings, diagrams, and 3D or higher-dimensional models. Traditionally, artefacts are generally accepted as sufficient to convey information when their visual content aligns with established conventions for representing design intent and demonstrating compliance with planning and building regulations. However, this research reveals that, as tools of communication, these artefacts remain arbitrary in nature. They lack a systematic foundation for tailoring information to meet explicit needs of recipients of the communication. As a result, the communicative function of the artefact tends to be generic rather than nuanced, often overlooking the importance of satisfying stakeholder-specific information requirements. Visual information is therefore arbitrarily conveyed which results in information being only partially relevant to stakeholders with diverse perspectives causing delays in the urban design process. On this premise, the research set out to develop a framework to analyse and evaluate artefacts that will enable better understanding of the process of aligning visual content with information needs in communication. The framework for the analysis and evaluation produced in this research is a logical system utilising a rule-based process to enable the system to be replicated, adapted and refined, and to ensure an evaluation result that is objective and evidence-based, a system prototype. The formulation of the analysis and evaluation schemas achieves a number of research objectives and validates the research hypothesis.

By employing shared parameters grounded in urban design logic, such as urban elements informed by Kevin Lynch's visual theory, this research demonstrates how visual information

in artefacts and stakeholder needs can be explicitly articulated. The integration of urban elements facilitates a logical basis for classifying visual information and supports the development of a taxonomy for graphical data.

The system validated the hypothesis by: 1) demonstrating that urban design artefact's visual information can be analysed and measured; 2) demonstrating that the visual communicative performance can be measured and correlated to stakeholder requirement conditions.

If graphical information embedded in visual communication artefacts—such as drawings, diagrams, and 3D or higher-dimensional models—can be systematically quantified and assessed against explicit information requirements of stakeholders, then the communicative value of those artefacts can also be effectively measured. It also highlights that graphical information can be quantified, measured and meaningfully compared with stakeholder requirements, provided both are expressed in logically consistent and comparable value types, demonstrating that relevance of information can be calculated. The process is algorithmic employing computation for graphical data analysis and assessing the fitness and relevance of data, producing results with numerical values. The three main processes in the system included the rationalising of design information using Lynch's urban elements, classifying data to be able to quantify and measure data contained in the artefact, and evaluating the data against explicit stakeholder requirements to test artefact fitness. The process of rationalising design information involves the review and identification of graphical objects contained in the artefact. The research manually carried out the review of select typical 2D artefacts, the collection of graphical content and classified these accordingly. For lack of a scientific basis and for the purpose of testing the system, the research manually allocated the values for stakeholders' requirements. These were made based on assumptions drawn from the areas of expertise of stakeholders who are generally involved in urban design, and as perceived

by the author from experience. Although parts of the research required manual intervention to test the system, the processes of measuring data within the artefact, assigning data values, and calculating data relevance were fully automated.

As a system prototype, the framework can be used to test alternative classification models grounded in different urban design logics. Designed to be adaptable, the system has modular components that function independently and can be adjusted or replaced without affecting the overall functionality. Additionally, to support user-driven analysis and evaluation of artefacts, the system incorporates calibration mechanisms, which are beneficial for customisation enabling the user to make adjustments as necessary. As a result, the research highlights fundamental principles and challenges the prevailing visual communication paradigm. The research also proposes a pathway for evidence-based evaluation of artefacts and highlights the gaps in stakeholder-centred communication models. It concurrently contributes to current research efforts in various areas of inquiry.

## **6.2 RESEARCH CONTRIBUTION**

### **6.2.1 Measuring Aesthetics**

Measuring aesthetics encompasses a significant body of literature and historical context, linked to quantitative theory that utilises numerical insights. Extensive research exists on aesthetics across various fields, including art, design, digital media cultures, dance and more broadly, communication. As aesthetics and visualisation have been researched together in various contexts, this research contributes to the topic in particular visualisation that relates to information with spatial and geographic references. As aesthetic systems have been presented in Algorithmic Aesthetics as a means to formalise and provide explicit rules for the description, interpretation and evaluation of any piece of work, this research highlights the significance of

aesthetics, its definition in the context of visual communication and how an aesthetic system can be achieved. The cross-tabulation of Lynch's urban elements and concepts from Stiny's Algebra of Shapes and graphical attributes provided the means to be able to describe, interpret and evaluate the artefact and formalised explicit rules for an aesthetic system that can be used for visualisations with spatial and geographic information. Evidently, the use of urban elements and geometric principles in this aesthetic system has enabled an easier approach to quantifying data thereby measuring aesthetics for visual communication. The research demonstrated how information in visual communication artefacts can be quantitatively measured and statistically analysed through a scientific basis and integrated theories to calculate aesthetic phenomena in visual communication artefacts.

### **6.2.2 User-centric Visual Communication for Collaborative Design Practice**

The system developed in this research can be turned into a tool or digital program. It can be used by anyone creating visual information, or evaluating its performance

It was also established in studies relating to information visualisation that the focus of user-centricity of visualisation is very limited. Not much work has been done to improve the usability of visualisations through the evaluation of visualisation designs so that designed visualisations are perceived meaningful and effective to the intended user as well as evaluation methods that can validate the effectiveness of visualisation designs (Shen et al, 2019).

This research highlights the lack of significant approaches for ensuring visual communication artefacts deliver information that is intentional and meets the information needs of stakeholders. The literature review indicates that lack of specificity in visual communication artefacts in urban design is well recognised. The study also identifies that methods for assessing how well conveyed information aligns with stakeholder needs are limited, which

makes optimising artefacts to increase their communicative value challenging. Without a scientific framework for measuring information and evaluating its efficacy, visual communication artefacts such as drawings in plans and sections, diagrams, and 3D or higher-dimensional models will be difficult to articulate with intent and be explicit for communication purposes. They will remain as generic communication tools. The framework developed in this research contributes to areas of inquiry relating to information mapping and user-centred visualisation.

The topic of data deluge is a persistent issue generally in any data processing scheme including visual communication artefacts as presented in this research, not to be confused with information visualisation, an area that has been studied intensively in the recent decades and relates to visualisation of data translated in graphic form. More broadly, visualisation includes the categorisation of input data that features data types, data attributes and application contexts (Wehrend & Lewis, 1990), and that is divided into two classes: (a) spatial data and (b) non-spatial data (Tory & Moller, 2004). Spatial data which is typically associated with a precise geometric or geographic specification requires a visual mapping process before visualisation. During which, the process involves the use of geographic information and considers the dimensions of spatial domain in 1D, 2D, 3D, etc (Chen & Floridi, 2013). Previous work has also presented visual communication pipelines of visualisations and illustrated in figures 6.1 and 6.2.

The significant parts of these pipelines for discussion is the involvement of perception and cognition in the models. The schema presented in this research is a departure from this involvement as the research proposed an independent study of user-centric visual communication from the cognitive process. There is precedent in this line of communication study such as Syntactic Structures by Noam Chomsky which argues for the independent study of syntax from meaning (Chomsky, 1957), a large part of the cognitive process.

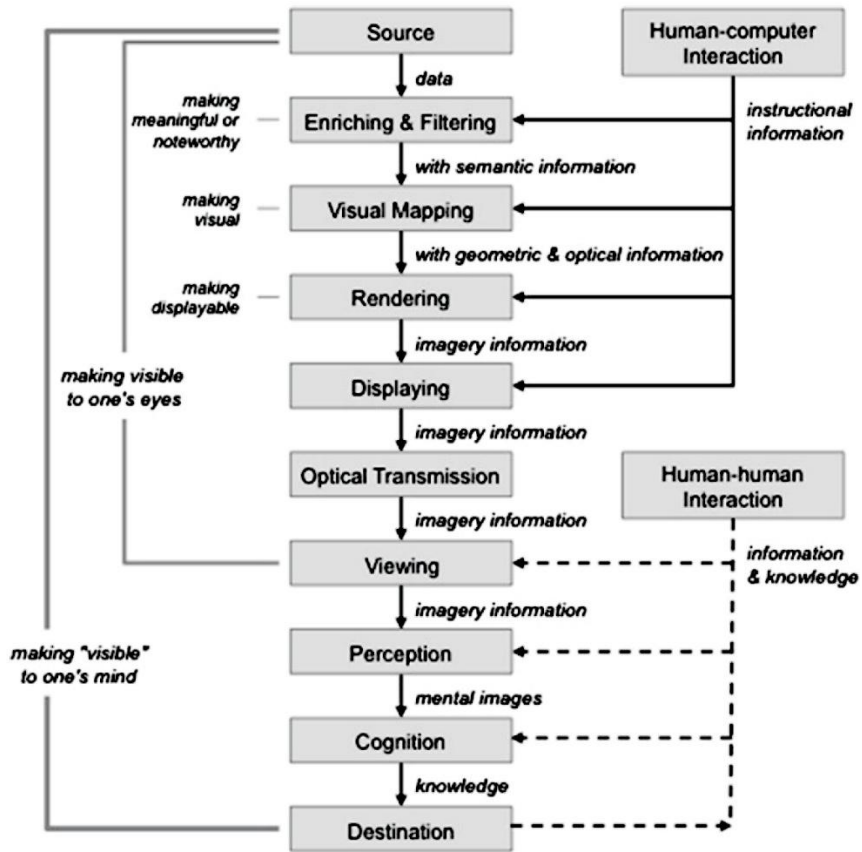


Figure 6.1: A typical visualisation pipeline. Chen & Floridi, 2013.

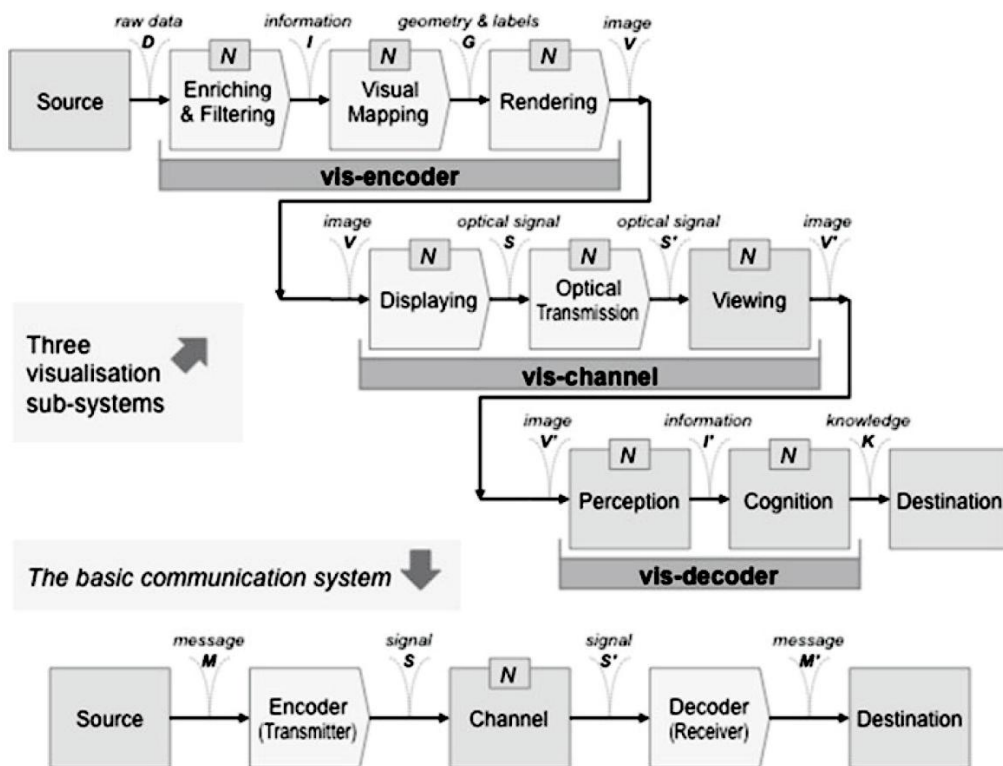


Figure 6.2: Abstract models of visualisation and communication. Chen & Floridi, 2013.

In *Syntactic Structures*, Chomsky concludes that grammar is autonomous and independent of meaning (Chomsky, 1957). Having the goal of developing a formula for precise, explicit and generative accounts that is intuition-free to resolve any ambiguity in the process, *Syntactic Structures* is rigorously mathematical and highly syntactic containing no cognitive representations. As stated in particular that ‘one may arrive at a grammar by intuition, guesswork, all sorts of partial methodological hints, reliance on past experience, etc... Our ultimate aim is to provide an objective, non-intuitive way to evaluate grammar once presented.’ (Chomsky, 1957). *Syntactic Structures* is therefore focused on the evaluation procedure as it was made clear that discovery methods do not form part of the process in order to distinguish different levels of representation. In much the same way, this research presents an approach to rethink ingrained conventions in visual communication and an approach to user-centricity in visualisation that has based its evaluation method to be distinct from direct cognitive or human input. As specialised professions or stakeholders with specific interests involved in the early phase of urban design can be logically identified, it can be conceived that assumptions as to the general nature of information requirements for stakeholder profiles can be formed. Thus, the criteria for visual communication evaluation in this research can be intuition-free and avoid relying on direct user input or any cognitive process, which is a novel approach.

As well, constraining information mapping to a limited urban elements agenda opens new ways for modelling user profiles, a growing area of inquiry. As modelling user profiles are application-specific and created specifically for a particular domain (Maria et al, 2007), this research highlights the significance of this burgeoning area and contributes to its application in visual communication in urban design.

### **6.2.3 Statistical Data Analysis of Visual Artefacts Technique & A Basis for an Ontological Framework**

Statistical image analysis plays a critical role in data processing in the field of computer vision and neural networks which lead to advances in the computer's ability to interpret images such as pictures and artwork. Rigorous statistical methods underpin this progress for computers to interpret and derive meaning from the images (Stork, 2023). This research used the algebra of shapes and graphical information attribution in the process for statistical data analysis of urban design artefacts. It demonstrated the effectiveness of this approach in quantifying graphical urban elements into measurable data and the basis for the computational process of the evaluation system. Consequently, the explicit categorisation and elaborate statistical process for classifying graphical shapes and attributes in the research schema opens new possibilities for developing ontologies for use in computerised systems.

### **6.2.4 General Insights in Urban Design Information & Communication Technology**

This section highlights the contribution of the study towards enhancing general understanding of visual communication artefacts in urban design. The study has performed a computational analysis of visual communication artefacts and evaluated their efficacy and relevancy in meeting stakeholders' information requirements. As a result, the study revealed the communicative inefficiencies inherent in current typical artefacts used in urban design and identified these as process centred. They are developed as artefacts that serve to present holistic design or convey details for design compliance and requirements, often missing specific information needs of stakeholders. Typical artefacts utilise varying levels of detail used for designing, mapping, analysis, collaboration and planning, and lacks a scientific metric for

evaluating their communicative impact in these activities. This research seeks to highlight the gap in this area to inform future efforts by those involved in ICT and visualisation development.

### **6.2.5 Societal Impact on Some Practical Output**

This research hopes to achieve improving communication, through better understanding of how visual information, which is a resource intensive process in industry, impacts the urban design collaborative process. As well, improving communication through better understanding of how visual information can be evaluated for their performance for better decision making.

## **6.3 FUTURE WORK**

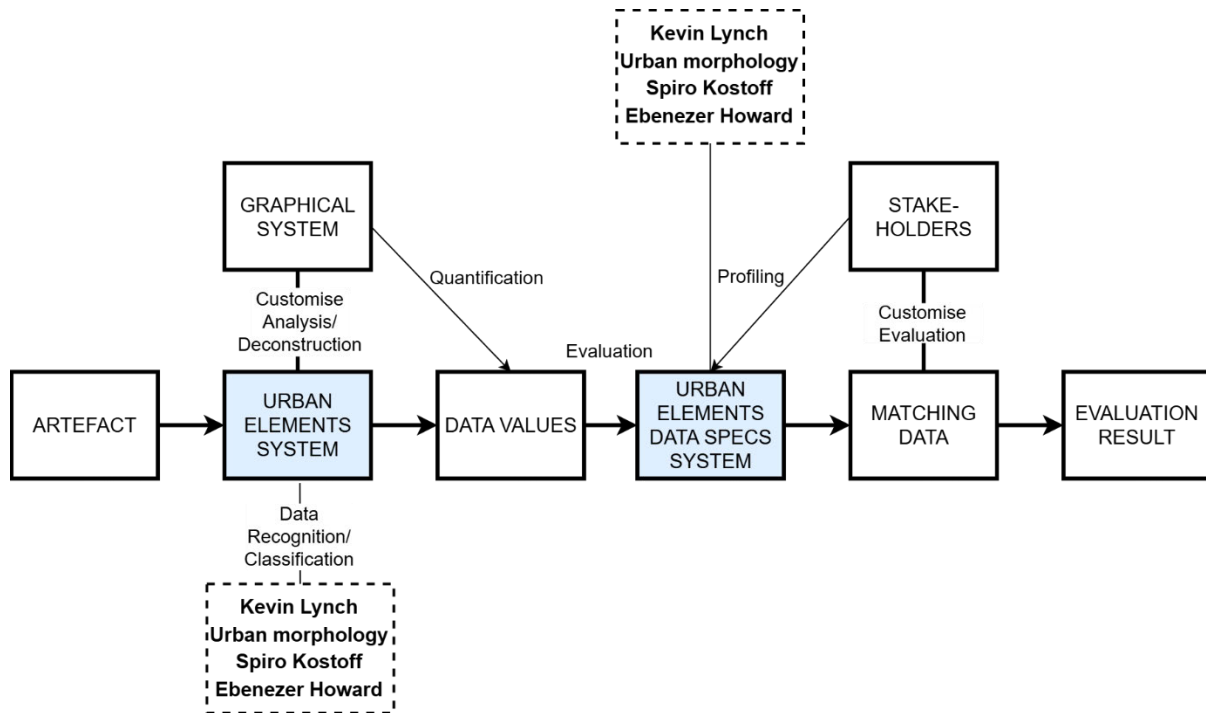
### **6.3.1 System Variables & Alternative Evaluation Models**

The system's features offer enhanced flexibility for customising analysis and evaluation processes. Its modular design, with distinct components that can be modified or replaced independently, ensures adaptability without compromising overall functionality. To gain a better understanding of the system, future research could explore the system's capacity to adapt to these changes, test suitable component alternatives and examine how the system can function under varying conditions.

#### **6.3.1.1 Urban element system variables**

A primary example is the urban element classification of path, edge, node, landmark, district and the additional element of zone, which can be replaced with other classification matrices. While Kevin Lynch's visual theory served as a logical basis in the research to analyse artefacts, other frameworks can be tested to gain alternative perspectives and insights relating to semantic systems, spatial cognition and visual language on urban form and design. For example, Spiro Kostof's analysis of city components offers a valuable alternative framework

for examining urban design artefacts. Adapting Kostof’s theory would fundamentally reshape the classification of urban elements to encompass streets, parks, public spaces, and transitional zones between urban and rural contexts.



artefact evaluation schema using alternative theoretical framework

**Figure 6.3:** A combination of dynamic stakeholder and artefact inputs.

Another viable framework is urban morphology to provide a structured classification matrix based on elements such as grids, lots, blocks, streets, buildings, and squares. Either framework will support the taxonomic organisation of detailed objects that can be detected in the artefacts—such as trees, vegetation, street furniture, vehicles, pedestrians, bridges, and cycleways—by enabling them to be classified systematically. For instance, trees may fall under the classification of Kostof’s ‘parks’, while street furniture could fall under multiple categories, including streets, parks, or public spaces. Bridges can be classified as urban divisions, and cycleways may be allocated under city or countryside classifications as appropriate. This illustrates how the urban elements system can work under other theoretical frameworks. The change in the classification system means that stakeholder needs must also be expressed in the

same value type, a requirement in the system to enable comparative data evaluation. This is illustrated in Figure 6.3. A critical consideration of future work is identifying which classification system provides a more effective framework and nuanced metrics for accurately describing stakeholder requirements in relation to their specific profiles.

### 6.3.1.2 A combination of alternative stakeholder input and artefact input

Social data and multi-agent systems from gaming environments present viable sources of structured information that can be explored as proxies for stakeholder input within the system illustrated in Figure 6.4. In gaming contexts, agents are typically categorised into roles—each defined by distinct rules, strategies, and objectives. Leveraging these gaming agents offers a conceptual platform to model stakeholder profiles using simple, rule-based behaviours that can reflect the roles of real-world urban planning and design professionals.

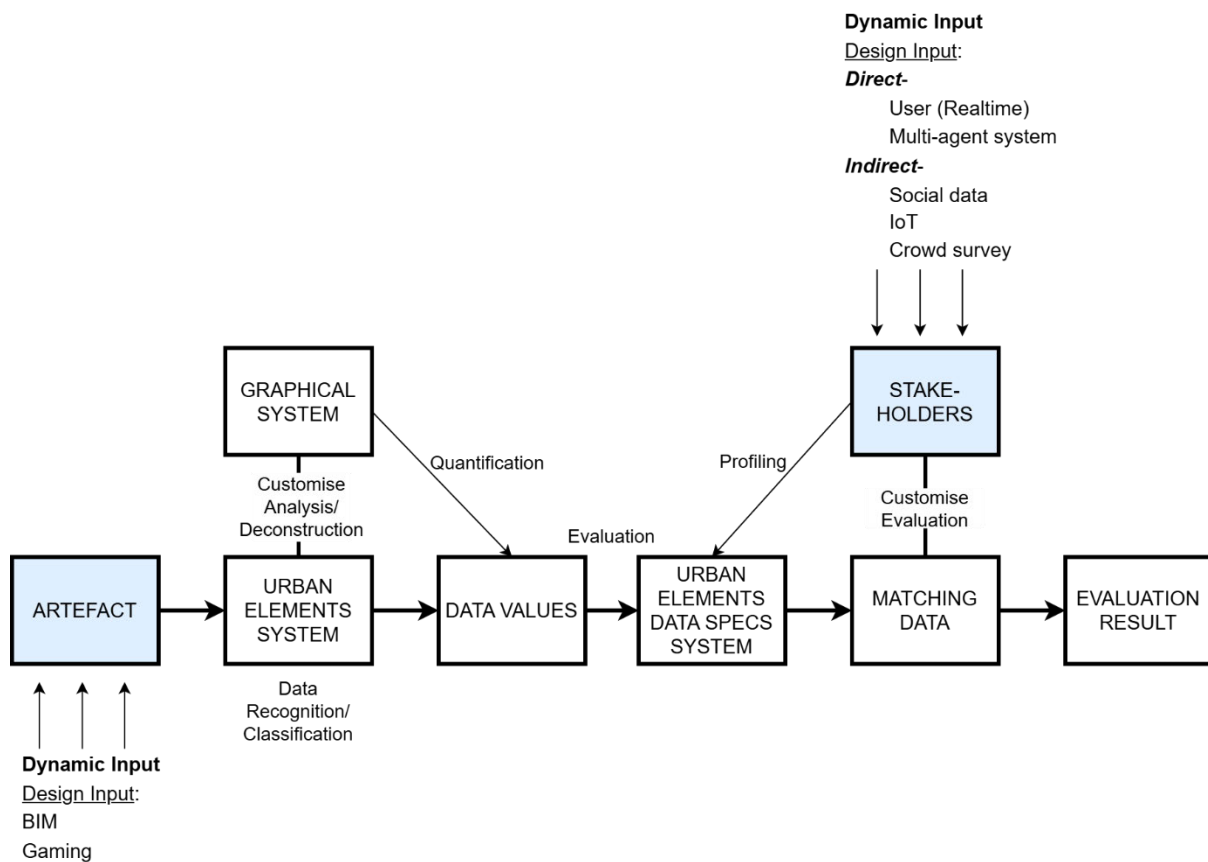


Figure 6.4: A combination of dynamic stakeholder and artefact inputs.

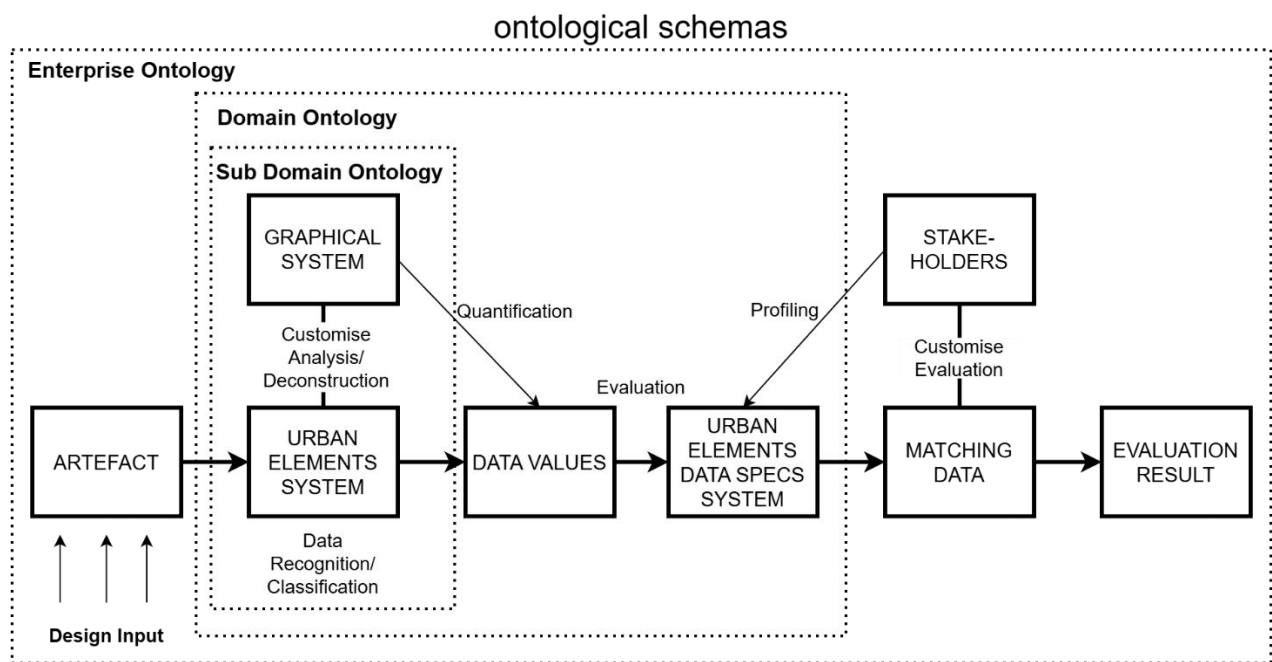
This approach also opens pathways for developing more sophisticated, adaptive algorithms—for artificial intelligence (AI) to evolve and refine stakeholder profile input by learning from patterns in user behaviour and interactions over time. Social data on the other hand, such as LinkedIn which is a platform focused on professional networking, also provide a viable source of information that can be filtered to produce prescribed roles and needs for urban planning and design professionals as stakeholder input. LinkedIn profiles in some cases also include BIM as software skills which could associate the profile’s skills with a required level of detail for use in the system. Further work on the system’s capability for dynamic input is also an area for future exploration.

### **6.3.2 Machine-Readable Semantics & Ontological Models**

Topological relationships for use in computer systems such as an ontological framework model is possible but not the focus of the research. The rule-based evaluation system prototype developed in this research offers a foundation for future work towards building a comprehensive ontological framework. Ontology-based frameworks have been developed for various uses in urban planning and design processes to semantically link any combination of people and systems (Metral, Falquet & Vonlanthen, 2007; Beirao, Duarte & Stouffs, 2011; Gil, 2020). Research efforts are ongoing in this area to provide a variety of workable models as “there is no generally agreed ontology of the entire city and planning process...” (Gil, 2020). Efforts to transform outdated urban design and planning systems are well documented. ‘The digitalisation of urban planning has been ongoing for decades’ (Nummi, Staffans & Helenius, 2023; Batty, 2021; Hersperger et al, 2021), and the issue of data interoperability has been recognised as a critical component in practical application. ‘...the aim has not been solely to define a machine-readable specification for plans, but to ensure that it is interoperable and structurally harmonised...’ (Nummi, Staffans & Helenius, 2023). It is further acknowledged in current research that although the structuring format of digital plans consists of machine-

readable data such as vector data, digital plans are not precisely defined. As illustrated in this research, an ontological approach linking disparate systems can offer novel solutions to issues of interoperability and definition strategy.

As such, to enable efficient information structuring and data organisation in urban planning and design, further exploration of various ontological approaches can significantly advance work in this area. The proposed research framework is capable of accommodating a range of ontological schemas. For instance, the data flow outlined in the research framework can be interpreted as an enterprise ontology, mapping holistic data relationships and various input strategies. This provides a structured method for managing the flow of information and the interrelationships between system components in a coherent and integrated manner. The extent of the enterprise ontology is illustrated in Figure 6.5.



**Figure 6.5:** A multi-layered ontological concept for artefact evaluation.

Another ontological schema identifiable within this enterprise environment is the use of urban elements to link the artefact, the evaluation process, and stakeholder needs. In this context, the urban elements system can be viewed as a domain ontology—serving as a universal

language that bridges these otherwise disparate components by translating varied information types into a common, comparable data format. As demonstrated in the research, employing urban elements as a shared semantic framework facilitates interoperability by standardising both the design concepts embedded in artefacts and the terminology used to articulate stakeholder needs into a consistent urban element data type. Urban elements will function as a language that can be universally understood and used across disparate systems. The extent of this domain ontology is illustrated in Figure 6.5.

Within the domain ontology, a more specific sub-domain ontology can be defined, focusing on the decomposition of urban elements into graphical data composed of geometric shapes and graphical information attributes. This process allows the conversion of urban elements into discrete geometric shapes—such as points, lines, planes and solids—and organising them into a structured format suitable for quantitative analysis. By applying principles of discrete geometry, this sub-domain ontology provides the explicit description, measurement, and classification of graphical content embedded in the artefact. For instance, the description for *Path* graphical data can be described according to the ontological schema illustrated in Figure 6.6, in which information can be made explicit and organised. Each layer of information can be adjusted, extended or replaced.

Given these concepts, a clear framework emerges for a multi-layered ontological approach that can underpin the structuring of complex visual data specific to urban design and planning.

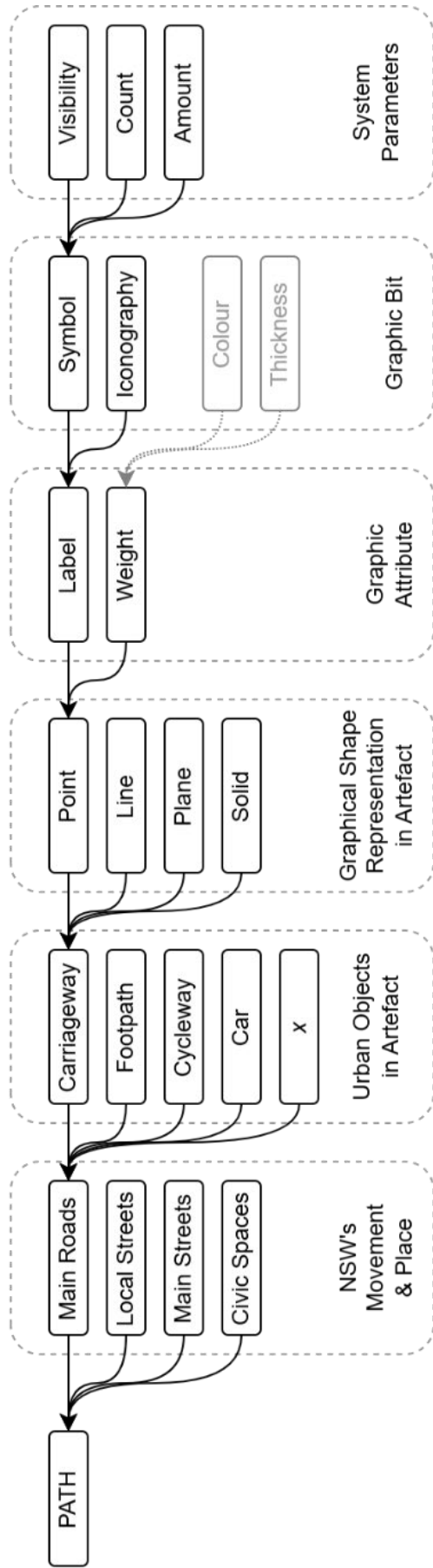
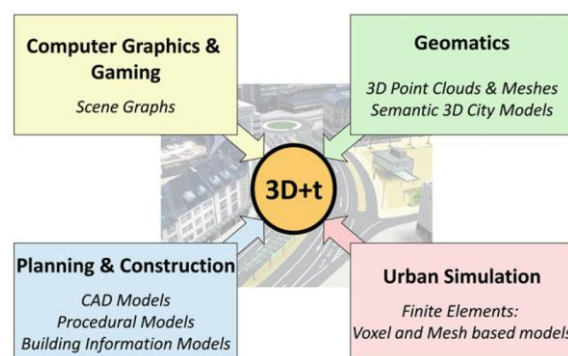


Figure 6.6: Ontological model concept for the urban element of path.

A multi-layered ontological framework can better support the development of a comprehensive data organisation strategy that is scalable and efficient, to link diverse types of information, system components, and operational processes in meaningful and coherent ways. The framework will also represent the knowledge and relationships within the ontological domain that is essential in the development of natural language processing, machine learning and decision support systems. Future work can focus on developing a more sophisticated multi-layered ontological framework that can underpin the reasoning in data management to enable more systematic and scalable approaches to data classification, description, quantification and interoperability. This also sets the foundation to enable visual information in artefacts to be suitable for the next generation of intelligent systems and advanced analytics.

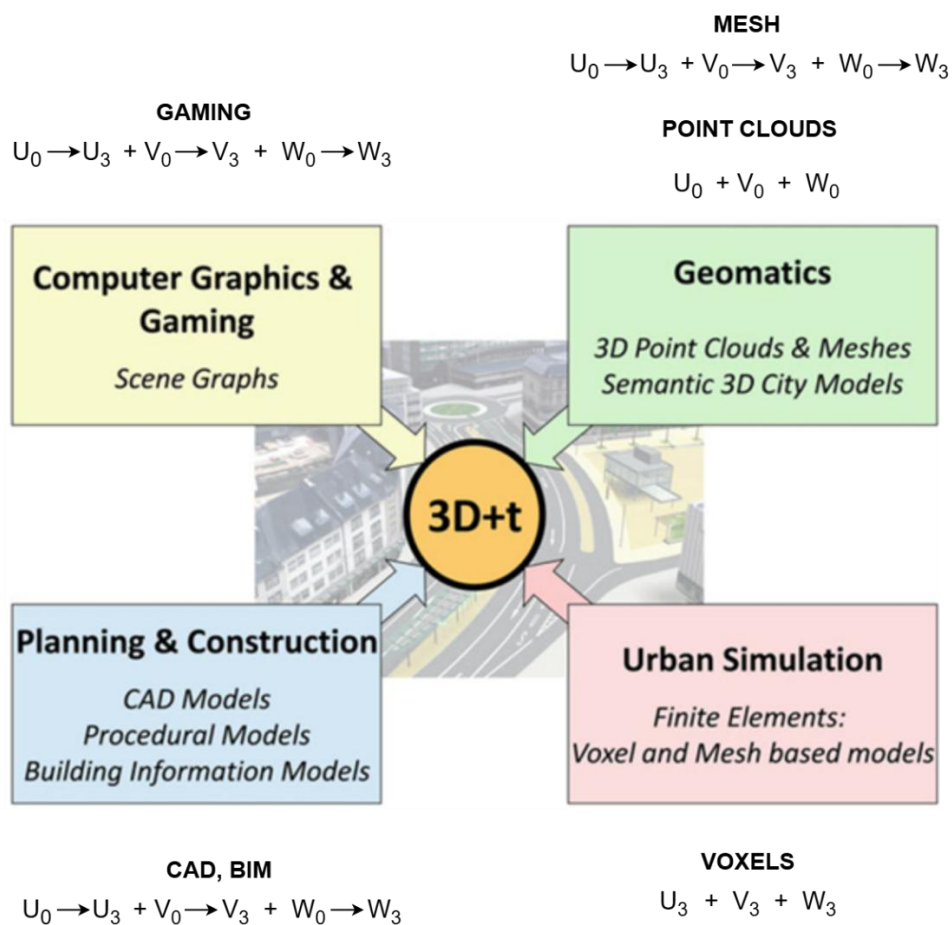
### 6.3.3 Higher-Dimensional Artefacts, Artefact Production Automation & Participatory Design Environments

Although the study demonstrated the evaluation of 2D artefacts, there is opportunity to explore the use of the system to include 3D and higher-dimensional formats. The system's features that can track information of 3D graphics and given that the same geometric principles can apply across most applications, the system can provide the foundation for future work focusing on 3D and higher dimensional artefacts.



**Figure 6.7:** Modelling techniques of urban 3D/4D models. Kolbe & Donaubaer, 2021.

Research in 3D urban modelling is ongoing and is carried out in various ways, employing different formal techniques and data representations (Kolbe & Donaubaauer, 2021). As illustrated in Figure 6.7, techniques for 3D urban models are shaped by at least four distinct disciplinary perspectives: computer graphics and gaming; geomatics (encompassing geoinformatics, geodesy, photogrammetry, and remote sensing); planning and construction (including civil engineering, architecture, urban and landscape planning); and urban and environmental simulation, with each field contributing its own tools, priorities, and conceptual frameworks. Considering the multitude of offerings in this digital landscape, future work can focus on bringing these to adhere to a common framework. As illustrated in Figure 6.9, the potential of a discrete geometric framework can widen the possibility to simplify 3D models into compatible and quantifiable data, and to address issues of interoperability.

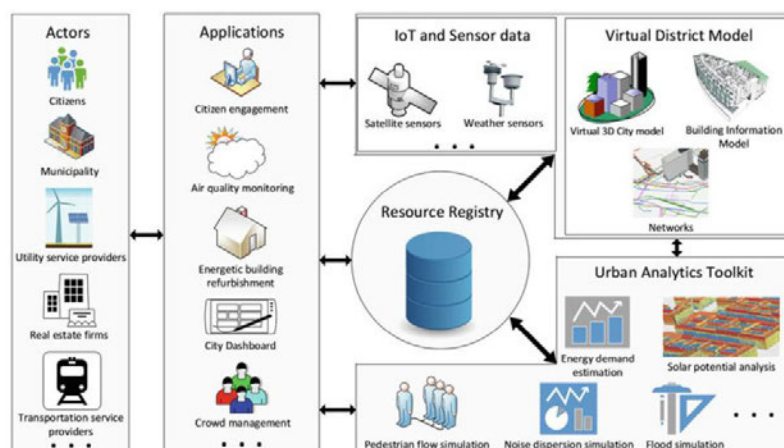


**Figure 6.8:** Kolbe & Donaubaauer’s 3D/4D city modeling and their shape algebras.

The capacity of the system to accommodate higher dimensional information is reflected in the research framework with the use of the algebra of shapes and its category for solids, with the algebra of  $U_{3,3}$ , as well as the graphical attribution of labels  $V_3$  and weights  $W_3$ . See Figure 6.8. Calibration Table 3 in the research incorporates value computations for 3D graphics, which reinforces the system's versatility to be able to calculate graphics of 3D. While the current experiments were confined to 2D artefacts, future work can focus on 3D as the system is designed to extend its capabilities to 3D graphical information. The research demonstrated in the experiments the system's ability to evaluate whether an artefact meets the needs of stakeholders, which prompts a rethink of how such artefacts can be improved and are created. The possibility for using the system to produce efficient artefacts can be the focus of future work. As the research experiments illustrated how manipulating graphical data can improve the scoring and ranking of the artefact, this process can offer insight into improving artefact development.

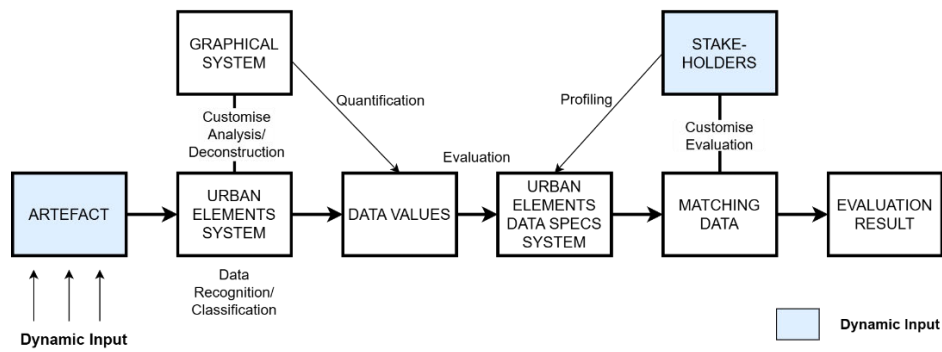
For instance, as a BIM model functions as a main and complete source of information related to a design project and is used to produce traditional drawings as artefacts for various professionals, it is possible the proposed system framework can improve the production of artefacts for more nuanced visual communication. Although drawing conventions persist in practice for approval and construction purposes, it can be further investigated how the process of filtering and organising information can be automated and more diverse to generate an effective communication artefact that will meet the precise need of a stakeholder or a profiled user. This can offer insights to those focused on advancing digital twin technology in terms of usability and addressing the issue of risks and other functional considerations. For example, in this scenario, stakeholders can access or be granted information according to their area of expertise, e.g. engineers can access lines only or  $U_1$  geometry, city planners can access spatial information such as zones or  $U_3$  geometry, builders like engineers can filter graphical data as

required, and so on, whilst real world values and geographic information can also link to and inform the system. By allowing information to be highlighted for the stakeholder during participatory design process, this can fast track shared understanding and improve design iterations. Similar to BIM models, research to advance city information modelling is ongoing and the common issues of having disparate systems and interoperability persist. A framework for a digital twin of a city district is presented as consisting of key elements and serves to integrate information in the context of smart urban districts. As illustrated in Figure 6.9, actors, software applications, sensor systems, urban analytics tools, a central resource registry that catalogues all distributed data sources, and a 3D virtual model of the district, which functions as the system's central component make up the Smart District Data Infrastructure (SDDI) framework (Kolbe & Donaubaauer, 2021).



**Figure 6.9:** Smart District Data Infrastructure components. Kolbe & Donaubaauer, 2021.

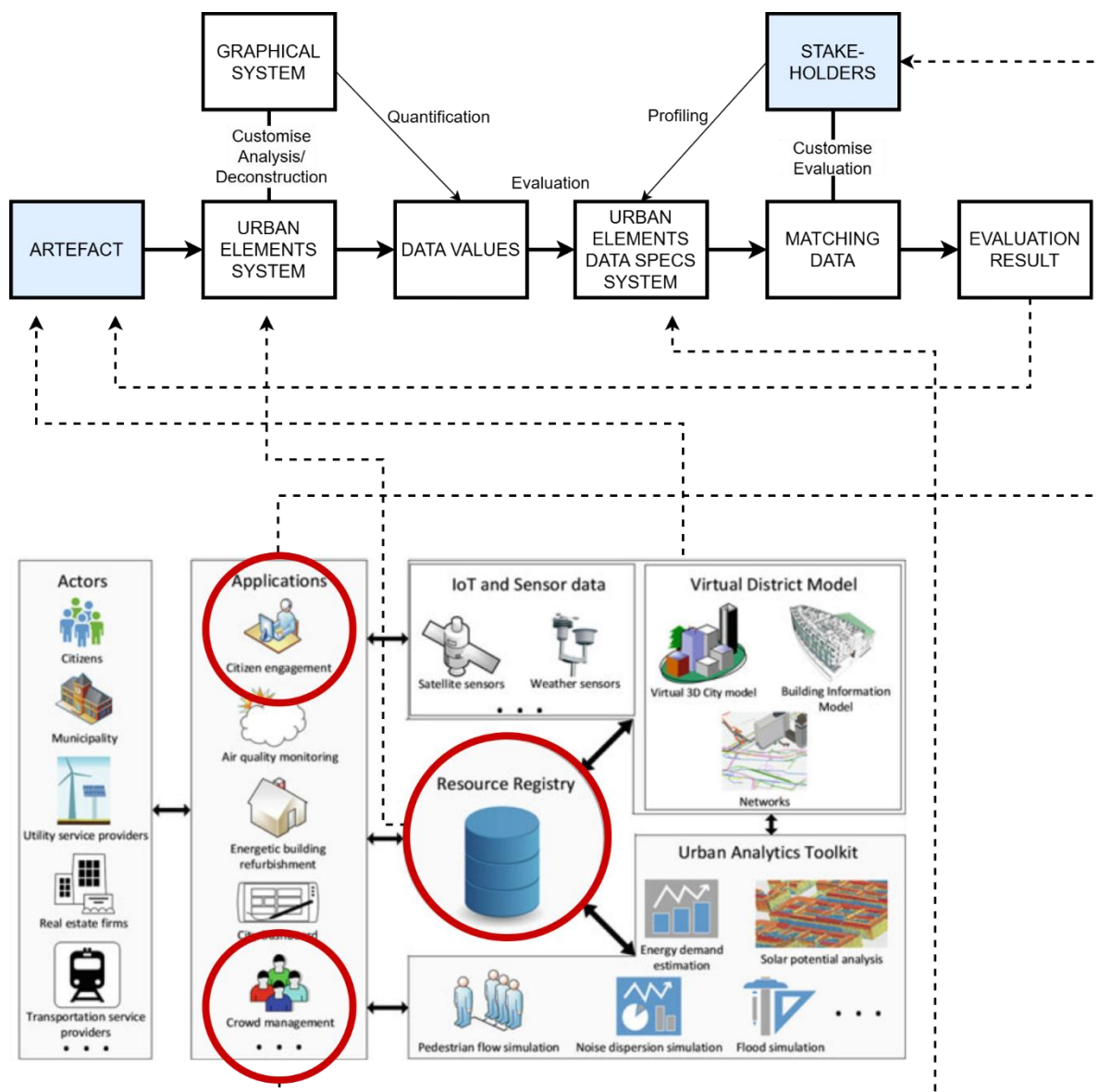
In this framework, to extract information for more tailored communication is still a challenge as this research highlights that stakeholders have diverse objectives and viewpoints, as well as varied levels of technical expertise, limiting the general usability of 3D city models. The artefact evaluation system developed in this research can offer insights into future work focused on developing an interface layer to make information more accessible and usable for stakeholders, as illustrated in Figure 6.10, in which dynamic inputs are featured.



**Figure 6.10:** Artefact evaluation schema with dynamic input

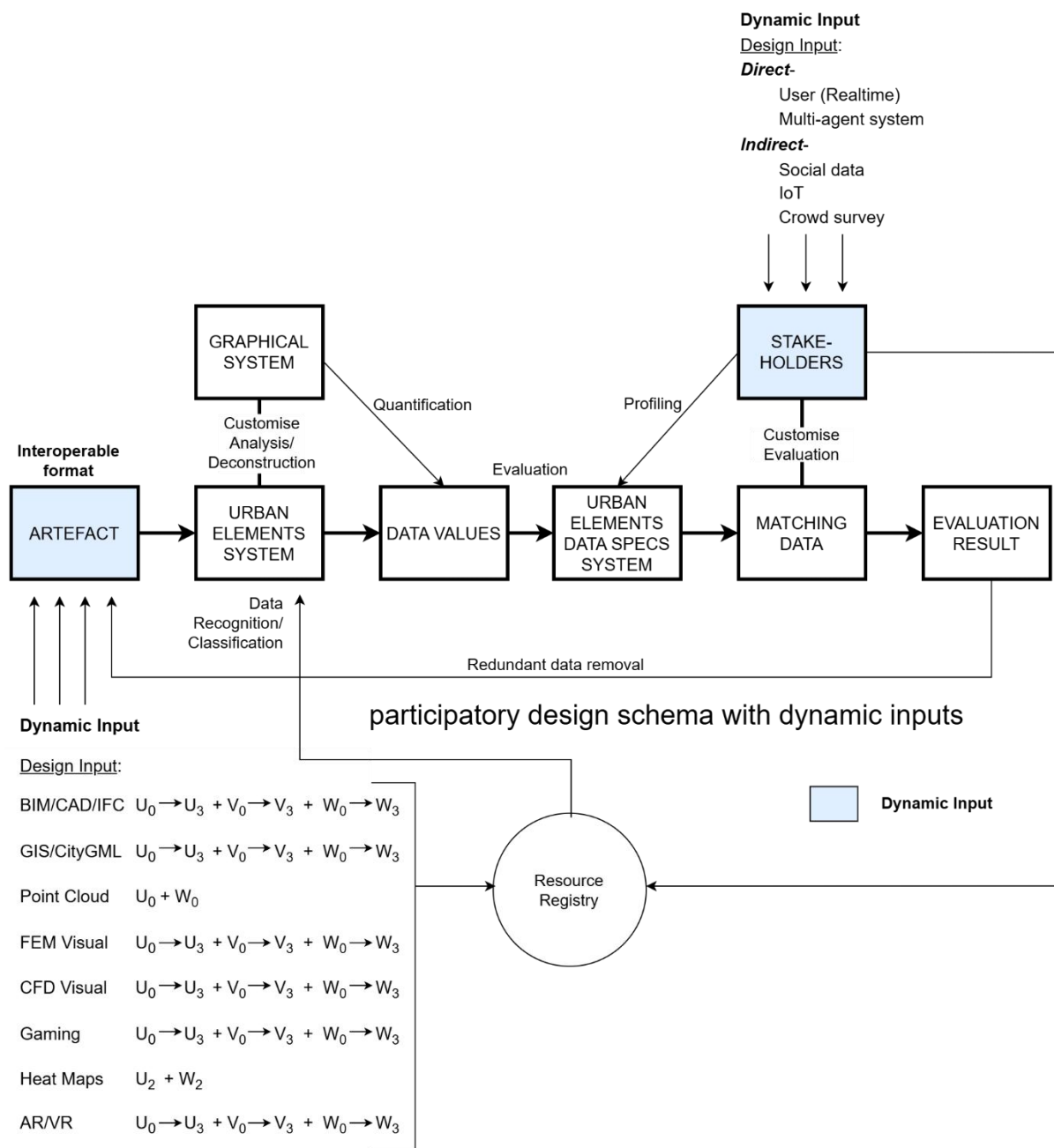
Figure 6.11 maps how the system can integrate into the SDDI framework. In this concept the artefact is shown as a segment derived from the virtual district model which is in a state already informed by Urban Analytics, IoT and Sensor data, and informed by the evaluation result of the system to culminate in an artefact that precisely meets the requirements of the stakeholder.

In the same way it can be speculated that the system can produce nuanced communication artefacts, it is also possible to imagine that a fully functioning system as presented in this research can enable various participatory design models. As a tool, the system can be used to support communication in participatory decision making. By allowing information to be highlighted for the stakeholder during participatory design process, this can fast track shared understanding and improve design iterations. For participatory design models to be possible, two areas of the system requires further exploration. First, the input of artefact is not in a static state. The artefact can be dynamic which will result in shifting graphical data values, requiring the system to be able to calculate in realtime. Second, the input of stakeholder needs are also not static, but dynamic and can be user driven, to allow for instant modelling of new states of the artefact in flux.



**Figure 6.11:** Kolbe & Donaubaue’s SDDI components and the artefact evaluation system

For instance, a cyclist can introduce new paths for cycleways which will increase the fitness of the artefact in the evaluation phase for a cyclist. In this scenario, stakeholders can influence the creation of the artefact in a dynamic state of iterative modelling, and the evaluation results inform the system in a loop, allowing for participatory design environments. The shift from the proposed static model framework introduces a dynamic model framework integrating real-time information inputs, as illustrated in Figure 6.12. Future work can focus on developing an advanced system that will allow information to loop and to allow the artefact to be in a state of flux.



**Figure 6.12:** Participatory design concept and the artefact development schema.

### 6.3.4 BIM & GIS

A topic that is gaining increasing relevance is the integration of BIM and GIS, a critical factor in advancing digitalisation in the architecture, engineering, construction and operations sector (AECO), and in the efforts to improve the decision-making process in all their phases

(Cepa et al,2024). Facilitating collaboration among all project stakeholders, promoting interoperability and enabling information exchange are persisting challenges identified in the research. The research also states that although BIM-GIS is getting closer to integration, the information transformation process between both IFC and CityGML, the BIM and GIS formats respectively, is complex and continues to be a challenge. The research emphasised that it is crucial that the BIM-GIS integration is extended to the AECO, meaning usability and accessibility are priorities for the multitude of stakeholders involved throughout the sector. The continued need for artefact generation reflects the practical reality that most stakeholders or urban actors typically require only specific, relevant information rather than full access to complex, detailed models all at once. To address these issues, this research opens new pathways for exploring alternative interoperability and accessibility strategies to manage information that can be derived from BIM, GIS and other proprietary applications. As demonstrated in the research visual information is discretised to its fundamental graphical elements of shapes and graphical attributions, which are universal and considered the building blocks of visual communication. Issues of information leakage is also identified as a challenge in information exchange processes when proprietary assets are involved. Hence, managing levels of development (LOD) with progressively increasing higher LODs, are often adopted according to the specific requirements at the time (Cepa et al,2024). ESRI, the leading company for GIS, developed open standard formats to package and distribute 3D scene layers in general. However, even though it is an open standard, only a few applications can operate with this format (Cepa et al,2024). As well, the Open Geospatial Consortium (OGC), the international body committed to creating open and interoperable standards, defined several standards including the 3D Scene Layer (I3S) format. This is used to stream and distribute large 3D GIS datasets across mobile, web, and desktop platforms. It efficiently stores and delivers large, diverse 3D geographic data for use in various workflows (OGC, 2021). While progress in these

areas is significant, the mobility of information will continue to require bite-sized and portable visual data. This is due to the multitude of stakeholders and urban actors in the AECO sector, each with varying levels of expertise and diverse interests in different aspects of the project and different types of information. Future work could focus on developing methods that leverage geometric elements, illustrated in Figure 6.13, to enhance the accessibility and usability of visual information across different user needs and platforms.

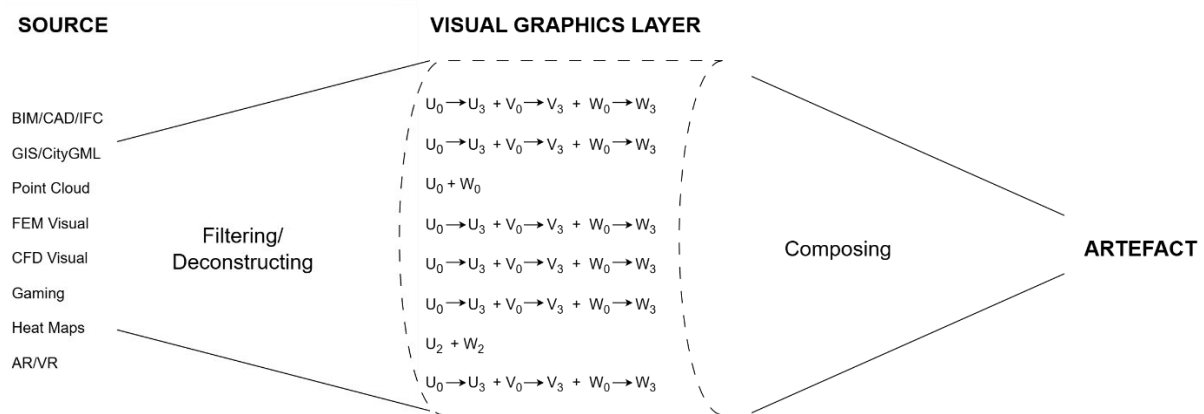


Figure 6.13: Visual graphics flow.

### 6.3.5 Calibration Automation, Computer Vision – Interactive Interfaces

The calibration mechanisms featured in the system provide an area for further exploration into interactive interfaces. The study demonstrated that the use of calibration mechanisms allowed for a highly adaptable system that can cater for user preferences. For instance, Calibration Table 1 can be adjusted to change the input variable of stakeholders. For lack of a profile database, the research manually allocated the values for this input variable. Calibration Table 1 can vary the number of stakeholders, and their requirements can be predefined based on professions and their focus requirements. Earlier discussions on direct or indirect such as social data or multi-agent systems as input are viable sources of information in this regard. However, an automated profiling system will require profile information needs to be categorised according to the system’s set of urban design classification. The second calibration feature in the system is defined by Calibration Table 2. This is also an input variable discussed

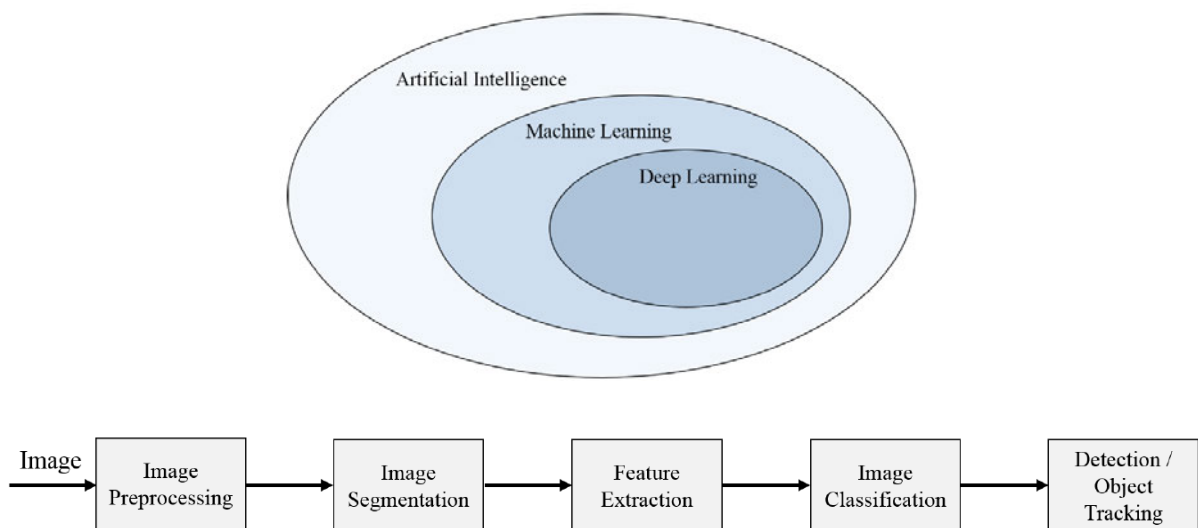
previously relating to the use of urban elements and classification of graphical objects found in the artefact. This feature can accommodate automated or manual adjustments to allow changes to the urban elements list or urban objects list, as well as changes to the ordering of graphical content, thus it can also be user driven.

Technological advancements in computer vision and object recognition in graphic formats can also advance the system to allow smart automated inputs. On this occasion, there are two factors that would require greater consideration. First refers to the way the computer can recognise the urban objects found in artefacts leading to the downstream data decomposition of geometric units. Second refers to the way the computer can classify urban objects leading to upstream data of urban elements. As demonstrated in the research urban objects in the artefact can relate to more than one urban element. For instance, road as an urban object can be classified under both path and edge urban elements, whilst a pedestrian urban object can be classified under path, edge and zone urban elements. Further research in this regard can focus on developing rules to automate this classification.

Another calibration feature is Calibration Table 3. The feature allows the value calculations and weightings for critical analysis, using graphical shapes such as points lines and planes, and graphical information attributions of labels and weights, to be dictated by the user. The calibration table enables the user to make adjustments to the values which dictate the level of importance for each shape, label and weight variables. As example, the research experiments used shape as 50%, label as 25% and weight as 25% for a total 100% information value. These can be adjusted for customised conditions and tailored to the user's needs. For instance, the user may require a highly stylised artefact effect, a condition that would require the value for weight to be greater as it refers to the use of weight graphical attributes such as colour, hatching, line types and line weights. Hence, an example of the change in value distribution such as: shape 25%, label 25% and weight 50%, will make the analysis more

suitable for diagrams and schematic renderings. Whereas engineering drawings will require values, such as shape 75%, label 10% and weight 15%, for having the focus on detailed linework. This calibration feature demonstrates the system’s flexibility in evaluating diverse graphic styles. Future work can focus on the development of user-friendly interfaces for the system calibration mechanism.

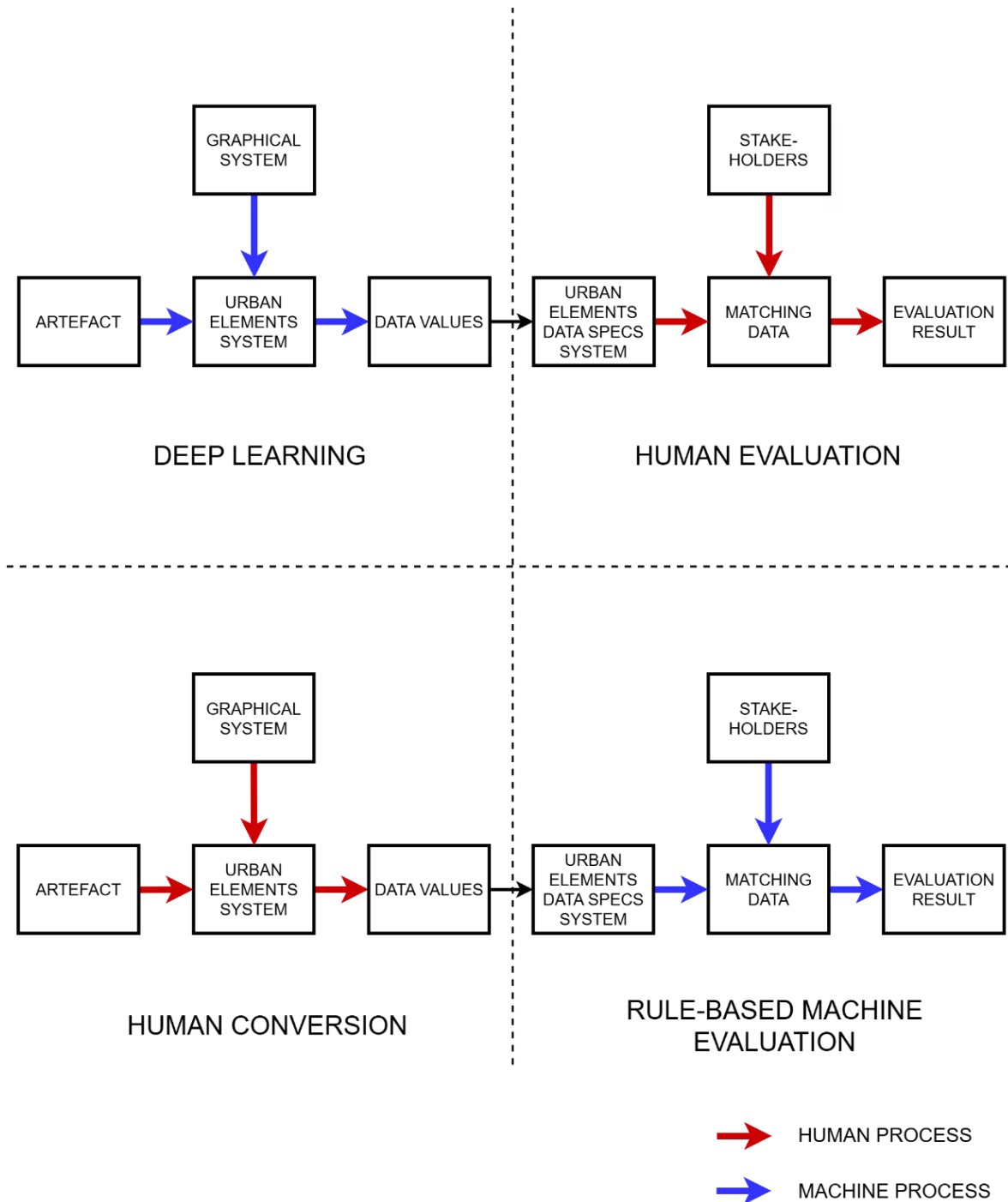
Alternatively, Calibration Tables 1 and 2 can benefit from technological advancements in Artificial Intelligence (AI). As AI seeks to replicate human intelligence, and vision plays a central role, the relationship between the two are important to understand. Computer vision which involves machine learning and deep learning, and are fundamental to its advancement, are key subsets of AI. The process by which computer vision processes images are illustrated in Figure 6.14 (Manakitsa et al, 2024).



**Figure 6.14:** Artificial intelligence subsets and image processing flow. Source: Manakitsa et al (2024).

As the artefact evaluation system points out the areas where advanced capabilities can offer enhancements to the system, future work can focus on image processing of artefacts specific to urban design and planning. For rule-based algorithms used in machine vision, the classifications and ontologies discussed earlier can play a key role in defining the rules. Whereas for deep learning, neural networks are trained to automatically learn features and

patterns from input data. Future work can focus on developing a combination using both rule-based AI and deep learning algorithms that can identify and learn from the rules in the visual data. A conceptual framework towards AI for further investigation is illustrated in Figure 6.15.



**Figure 6.15:** A framework towards AI for further investigation.



## Chapter 7: References

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- Barr, R.E. and Juricic, D., 1994. From drafting to modern design representation: The evolution of engineering design graphics. *Journal of Engineering Education*, 83(3), pp.263-270.
- Batty, M., Chapman, D., Evans, S., Haklay, M., Kueppers, S., Shiode, N., Smith, A. and Torrens, P.M., 2001. Visualizing the city: communicating urban design to planners and decision-makers.
- Batty, M., 2021. Defining urban science. *Urban informatics*, pp.15-28.
- Beirão, J.N., Duarte, J.P. and Stouffs, R., 2011, 'Creating specific grammars with generic grammars: towards flexible urban design', *Nexus Network Journal*, 13, pp.73-111.
- Bieda, A., Bydłosz, J., Parzych, P., Pukanská, K. and Wójciak, E., 2020. 3D technologies as the future of spatial planning: The example of Krakow. *Geomatics and environmental engineering*, 14(1), pp.15-33.
- Birkhoff, G.D., 1933, *Aesthetic measure*. Havard University.
- Bo, Y., Yu, J. and Zhang, K., 2018. Computational aesthetics and applications. *Visual computing for industry, biomedicine, and art*, 1, pp.1-19.
- Carlsson, M.K., 2013, *Stratified, de-stratified, and hybrid GIS: organizing a cross-disciplinary territory for design*, (Doctoral dissertation, Massachusetts Institute of Technology).
- Carmona, M., 2021, *Public places urban spaces: The dimensions of urban design*, Routledge.
- Carmo, M. ed., 2013, *The digital turn in architecture 1992-2012*, John Wiley & Sons.
- Cepa, J.J., Alberti, M.G., Pavón, R.M. and Calvo, J.A., 2024. Integrating BIM and GIS for an Existing Infrastructure. *Applied Sciences*, 14(23), p.10962.
- Chen, M. and Floridi, L., 2013. An analysis of information visualisation. *Synthese*, 190, pp.3421-3438.
- Christmann, G., Singh, A., Stollmann, J. and Bernhardt, C., 2020, 'Visual communication in urban design and planning: The impact of mediatisation (s) on the construction of urban futures', *Urban Planning*, 5(2), pp.1-9.
- Craig, R.T., 2008, 'Communication as a field and discipline', *The international encyclopedia of communication*.

- Cronan, D., Trammell, E.J. and Kliskey, A., 2022, 'Images to evoke decision-making: Building compelling representations for stakeholder-driven futures', *Sustainability*, 14(5), p.2980.
- Cuthbert, A.R., 2007, 'Urban design: requiem for an era—review and critique of the last 50 years', *Urban Design International*, 12, pp.177-223.
- Dangermond, J., 2012. GIS and The City 2.0. *Foundations of Urban and Regional Information Systems and Geographic Information Systems and Science*, p.270.
- De Siqueira, G., Malaj, S. and Hamdani, M., 2022. Digitalization, Participation and Interaction: Towards More Inclusive Tools in Urban Design—A Literature Review. *Sustainability*, 14(8), p.4514.
- Giaveno, S., 2021. Smart City and Digital Twins: Definitions, Methodologies, and Applications. In *Handbook of Research on Developing Smart Cities Based on Digital Twins* (pp. 243-264). IGI Global.
- Gil, J., 2020, 'City information modelling: A conceptual framework for research and practice in digital urban planning', *Built Environment*, 46(4), pp.501-527.
- Giralt-Miracle, D., 2015. *Essential Gaudi*. Libros de Vanguardia.
- Greenfield, G., 2005, On the Origins of the Term "Computational Aesthetics". <https://doi.org/10.2312/COMPAESTH/COMPAESTH05/009-012>. Accessed 23 October 2023.
- Hasler, S., Chenal, J. and Soutter, M., 2017, 'Digital tools as a means to foster inclusive, data-informed urban planning', *Civil Engineering and Architecture*, 5(6), pp.230-239.
- Hazewinkel, M., 1989. CWI, PO Box 4079, 1009AB Amsterdam, The Netherlands. *Newton's Method and Dynamical Systems*, 13, pp.203-219.
- Hersperger, A.M., Grădinaru, S.R., Pierri Daunt, A.B., Imhof, C.S. and Fan, P., 2021. Landscape ecological concepts in planning: review of recent developments. *Landscape ecology*, pp.1-17.
- Hoenig, F., 2005. Defining computational aesthetics. *Computational aesthetics in graphics, visualization and imaging, 2005*, pp.13-18.
- Jacobs, A.B., 1991. *Great Streets*.
- Kolbe, T.H. and Donaubaue, A., 2021. Semantic 3D city modeling and BIM. *Urban informatics*, pp.609-636.

- Kostof, S., 1991, *The city shaped* (pp. 9-39). Boston, MA: Little, Brown and Company.
- Lang, J., 2009, 'International urban design: Theory and practice', *Proceedings of the Institution of Civil Engineers-Urban Design and Planning*, 162(1), pp.7-17.
- Langendorf, R., 1992, 'The 1990s: information systems and computer visualization for urban design, planning, and management', *Environment and Planning B: Planning and Design*, 19(6), pp.723-738.
- Lynch, K., 1960. *The image of the city*. MIT press.
- Manakitsa, N., Maraslidis, G.S., Moysis, L. and Fragulis, G.F., 2024. A review of machine learning and deep learning for object detection, semantic segmentation, and human action recognition in machine and robotic vision. *Technologies*, 12(2), p.15.
- Mandanipour, A., 1997, *Ambiguities of urban design*, *Town planning review*, 68(3), p.363.
- Maria, G., Akriki, K., Costas, V., George, L. and Constantin, H., 2007. Creating an ontology for the user profile: Method and applications. In *Proceedings AI\* AI Workshop RCIS* (pp. 407-412).
- McKinney, K., Kim, J., Fischer, M. and Howard, C., 1996. Interactive 4d-cad. *Computing in Civil Engineering*, 20, pp.381-389.
- Métral, C., Falquet, G. and Vonlanthen, M., 2007, 'An ontology-based model for urban planning communication', *Ontologies for urban development* (pp. 61-72). Springer, Berlin, Heidelberg.
- Migliari, R., 2012, 'Descriptive geometry: from its past to its future', *Nexus Network Journal*, 14, pp.555-571.
- Muhly, P.S., 1978. Ergodic Hardy spaces and duality. *Michigan Mathematical Journal*, 25(3), pp.317-323.
- Movement, 2012, In *Merriam-Webster's Dictionary*, Merriam-Webster, Springfield, Massachusetts. <http://www.merriam-webster.com/dictionary/movement>. Accessed 20 December 2023.
- Nummi, P., Staffans, A. and Helenius, O., 2023, 'Digitalizing planning culture: A change towards information model-based planning in Finland', *Journal of Urban Management*, 12(1), pp.44-56.

- Open Geospatial Consortium, 2021, *OGC Indexed 3D Scene Layer (I3S) and Scene Layer Package (slpk) Format Community Standard Version 1.2*; Reed, C., Belayneh, T., Eds.; OGC® Community Standard: Arlington, TX, USA. <http://www.opengis.net/doc/CS/i3s/1.2>. Accessed 1 May 2025.
- Patterson, R.E., Blaha, L.M., Grinstein, G.G., Liggett, K.K., Kaveney, D.E., Sheldon, K.C., Havig, P.R. and Moore, J.A., 2014. A human cognition framework for information visualization. *Computers & Graphics*, 42, pp.42-58.
- Ricci, A., 1973, 'A constructive geometry for computer graphics', *The Computer Journal*, 16(2), pp.157-160.
- Rigau, J., Feixas, M. and Sbert, M., 2007, June. Conceptualizing Birkhoff's Aesthetic Measure Using Shannon Entropy and Kolmogorov Complexity. In *CAE* (pp. 105-112). Senescu, R.R. and Haymaker, J.R., 2013. Evaluating and improving the effectiveness and efficiency of design process communication. *Advanced Engineering Informatics*, 27(2), pp.299-313.
- Shannon, C.E., 1948. A mathematical theory of communication. *The Bell system technical journal*, 27(3), pp.379-423.
- Shen, H., Bednarz, T., Nguyen, H., Feng, F., Wyeld, T., Hoek, P.J. and Lo, E.H., 2019. Information visualisation methods and techniques: State-of-the-art and future directions. *Journal of Industrial Information Integration*, 16, p.100102.
- Sternberg, E., 2000, 'An integrative theory of urban design', *Journal of the American Planning Association*, 66(3), pp.265-278.
- Stiny, G., 1980. Introduction to shape and shape grammars. *Environment and planning B: planning and design*, 7(3), pp.343-351.
- Stiny, G., 2006. *Shape: talking about seeing and doing*. MIT Press.
- Stiny, G. and Gips, J., 1978. *Algorithmic aesthetics: computer models for criticism and design in the arts*. Univ of California Press.
- Stork, D.G., 2023, *Deep Network-Based Computational Transfer of Artistic Style in Art Analysis*, Modeling Visual Aesthetics, Emotion, and Artistic Style (pp. 351-367), Cham: Springer International Publishing.
- Stouffs, R., 1994. *The algebra of shapes*. Carnegie Mellon University.

- Stouffs, R., 2012. On shape grammars, color grammars and sortal grammars. *Proceedings of eCAADe 2012, 1*, pp.479-487.
- Tambouris, E., Dalakiouridou, E., Panopoulou, E. and Tarabanis, K., 2011. Evaluation of an argument visualisation platform by experts and policy makers. In *Electronic Participation: Third IFIP WG 8.5 International Conference, ePart 2011, Delft, The Netherlands, August 29–September 1, 2011. Proceedings 3* (pp. 74-86). Springer Berlin Heidelberg.
- Thompson, P.M. (2023) 'HUMAN FACTORS IN DATA VISUALIZATION', in *Visualization Design for Communicating Defence Investment Uncertainty and Risk*. Institute for Defense Analyses
- Tomlin, C.D., Fundamentals of Geospatial Algorithm Design. *Foundations of Urban and Regional Information Systems and Geographic Information Systems and Science*, p.236.
- Tory, M. and Moller, T., 2004, October. Rethinking visualization: A high-level taxonomy. In *IEEE symposium on information visualization* (pp. 151-158). IEEE.
- Wehrend, S. and Lewis, C., 1990, October. A problem-oriented classification of visualization techniques. In *Proceedings of the First IEEE Conference on Visualization: Visualization90* (pp. 139-143). IEEE.