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Point Clouds as a Representative and Performative Format for Landscape Architecture
- A Case Study of the Ciliwung River in Jakarta, Indonesia

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presented by

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Abstract

This thesis investigates the opportunities and challenges of using point clouds simultaneously as a representative and performative format for landscape architecture. It does so by applying developed tools and workflows on the ailing Ciliwung River which flows through the capital of Indonesia, Jakarta. The river itself has borne witness to an alarming urban growth with a multitude of factors placing tremendous pressure on it which has resulting in an increase in the frequency and magnitude of the devastating floods. In an attempt to find a possible solution to this, the thesis works within a multidisciplinary team to develop and test different possible flood mitigation scenarios built upon a point cloud workflow.

Point clouds are a digital collection of three dimensional coordinates or points often with additional metadata attached to each point and are a result of emerging reality capture techniques. This new technology allows us to directly digitize the landscape around us thereby completely altering the way in which we obtain topographical and spatial data of our landscapes. The tools developed by the thesis provide the possibility of embedding alternative scenarios into these reality captured base datasets in an attempt to not only visually represent these scenarios but also to directly interface them with quantitative performance models to test their effectiveness. In the process of doing this, it was found that with the current limitations, attempting to create realistic representations of landscape architecture with point clouds is not only a difficult process but also an inefficient one when compared to already established workflows.

In contrast, the thesis discovered that if realistic representations are not required, abstracted point cloud representations can readily integrate with quantitative performance models. The discrete nature of the points and their associated attributes within a point cloud allow analytical models to efficiently retrieve the required coordinate and metadata information from the base dataset. This opens up the possibility for early stage design testing in which multiple alternative scenarios can be tested and cross referenced against each other to find an optimal solution. Two such analytical models were applied; the first being the use a hydrodynamic simulations to test the flood mitigation potentials of the proposed scenarios; the second was the calculation of landscape metrics from which it was hoped that a correlation between the flood simulation results could be established with the quantifiable changes in landscape structure. This however was not the case, while the flood simulations hinted at possible alternatives to the massive canalization plans put forth by the government, the thesis found it challenging to use landscape metrics to inform of any mitigation solutions. Similarly disappointing was the fact that our findings ultimately were unable to alter the fate of the river and canalization works continue as planned.

Still the thesis is optimistic about the potentials of adopting a point cloud workflow and while there are undoubtedly technical difficulties yet to be overcome, it is envisioned that a unified hardware and software ecosystem can be developed around point cloud data. One which allows for point clouds to be efficiently stored and retrieved while allowing for dynamic modifications to the base data which is fully integrated with quantitative testing models. While this reality is yet to be realized, the technology is already mature enough for landscape architects to begin serious considerations into the permanent adoption of point clouds as the three dimensional format which bridges landscape representations with performance testing.

Keywords: Point Clouds, Landscape Architecture, Landscape Representation, Landscape Performance

Abstrait

Cette thèse fait l'étude des opportunités et des défis concernant l'utilisation de nuages de points en tant que schéma représentatif et performant de l'architecture du paysage. Cela a été réalisé en s'appuyant sur des outils et des travaux réalisés sur le Ciliwung, un fleuve mourant qui traverse Jakarta, la capitale de l'Indonésie. Ce fleuve a subit une croissance urbaine importante avec une multitude de facteurs, ce qui a entraîné une augmentation de la fréquence et de l'ampleur des inondations dévastatrices. En tentant de trouver une solution à ces inondations, cette thèse s'inscrit au sein d'une équipe multidisciplinaire pour développer et tester différents scénarios d'atténuation en s'appuyant sur un système à base de nuages de points.

Les nuages de points sont des ensembles numériques de coordonnées tridimensionnelles, ou des points contenant souvent des informations supplémentaires, et qui sont le résultat de nouvelles techniques de capture de la réalité. Cette nouvelle technologie nous permet de numériser directement le paysage autour de nous, changeant ainsi complètement la façon dont nous obtenons les données spatiales et topographiques des paysages. Les outils développés au cours de cette thèse offrent la possibilité d'intégrer des scénarios alternatifs dans ces ensembles de données de base, capturés de la réalité dans l'intention de représenter non seulement ces scénarios visuellement mais aussi de les interfacer directement avec des modèles quantitatifs de performance pour tester leur efficacité. En effectuant ces représentations, il a été constaté qu'avec les limitations actuelles, la tentative de créer des représentations réalistes de l'architecture du paysage avec des nuages de points n'est pas seulement difficile mais également pas suffisamment efficace par rapport aux travaux déjà réalisés.

En revanche, cette thèse montre que si des représentations réalistes ne sont pas requises, les représentations abstraites de nuages de points peuvent facilement s'intégrer à des modèles quantitatifs de performance. La nature discrète des points et de leurs attributs au sein d'un nuage de points permet aux modèles analytiques de récupérer efficacement les informations des coordonnées et des métadonnées requises sur un ensemble de données de base. Cela offre des possibilités pour les tests préliminaires de conception dans lesquels plusieurs scénarios alternatifs peuvent être testés et recoupés les uns avec les autres de manière à trouver une solution optimale. Deux de ces modèles analytiques ont été appliqués. Le premier est l'utilisation des simulations hydrodynamiques pour tester les atténuations potentielles des inondations des scénarios proposés. Le second concerne le calcul des mesures du paysage, dont on espérait que les résultats de simulations d'inondations pourraient être corrélés avec les changements quantifiables dans la structure du paysage. Ce ne fut cependant pas le cas. Tandis que les simulations d'inondations font allusion à des alternatives possibles aux plans de canalisations massives mises en œuvre par le gouvernement, cette thèse montre que l'utilisation des métriques du paysage pour trouver des solutions d'atténuation est difficile. En fin de compte, les résultats décevants obtenus n'auront pas permis de modifier le sort de la rivière, et les travaux de canalisation se poursuivent.

Malgré tout, cette thèse reste optimiste en ce qui concerne les travaux s'appuyant sur l'utilisation de nuages de points, bien qu'il reste encore plusieurs difficultés techniques à surmonter. Le développement de systèmes combinant à la fois l'électronique et l'informatique ont été envisagés autour de ces techniques. De tels systèmes permettraient de stocker et de restituer efficacement les données des nuages de points, tout en permettant d'effectuer des modifications dynamiques aux données de bases qui sont entièrement intégrées aux modèles de tests quantitatifs. Bien que cette solution ne soit pas encore d'actualité, la technologie est suffisamment avancée pour que les architectes paysagistes puissent considérer sérieusement d'adopter de manière permanente les nuages de points comme format de représentation tridimensionnel, alliant ainsi les représentations paysagères avec les tests de performance.

Mots clés: Nuage de Points, Architecture du Paysage, Représentation du Paysage, Performance de Paysage

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Ervine Lin / 08 Dec 2015

Publications

Portions of the thesis were derived from previously published works. More prominently, the tools discussed in chapter 2.3 were extended from work previously presented (Lin and Girot 2014), while the corridor scale scenarios and their respective hydraulic simulation test results described in chapters 3.4.2 and 4.3 were also published (Lin et al. 2016).

Main Author

Lin, Ervine and Christophe Girot (2014). 'Point Cloud Components: Tools for the Representation of Large Scale Landscape Architectural Projects', in *Peer Reviewed Proceedings of Digital Landscape Architecture, 2014*. Zurich, Switzerland: 9783879075300.

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Organisation of Thesis

The thesis is organized into 6 different chapters. Chapter 1 introduces the main drivers behind the research as well as outlines the conditions of the site and the underlying theoretical framework the thesis builds itself upon. Chapter 2 details the methodological approach the thesis takes in attempting to uncover the capabilities of point cloud models and their use in landscape architecture. Chapter 3 details the initial technical aspects of the work which include data collection, tool development and the performance testing platforms utilised during the course of the thesis. Chapter 4 highlights the scenario development process at the site and corridor scale as well as demonstrates the results from applying quantitative performative models to it. Chapter 5 concludes the thesis by discussing the nuances of attempting to utilise point clouds in landscape architecture as well as the outlook of the work in general. Chapter 6 is the appendix which provides more details to the tools developed.

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Chapter 1 - Introduction

1.1 Motivation

By 2050, an additional 2.5 billion people, resulting in a total of 66 percent of the world's population, is projected to reside in urban areas with a glaring majority of this increase concentrated in Asia and Africa (United Nations 2014). This massive urban transition coincides with an unprecedented expansion of built-up land which has resulted in ramifications to the local-regional climate, pollution, water quality and availability, arable land as well as the livelihoods of people in the region (Schneider et al. 2015). Much of this growth occurs in the "mega-deltas cities" which have historically conglomerated people, resources and economic activities, a trend which increasingly places them at risk to environmental hazards (Seto 2011) and has contributed to rivers and wetlands becoming one of the most threatened ecosystems in the world (Tockner and Stanford 2002; Malmqvist and Rundle 2002).

Flooding, which has devastated many Asian cities in recent years (Chan et al. 2012), is one of these environmental hazards and is seen resulting from a rapidly converging combination of climate change, sea level rise, intense storm surges as well as ceaseless urban growth (Fuchs et al. 2011). Floods in the Ganges-Brahmaputra Delta in 1970 and 1991 are estimated to have had a death toll of 300,000 and 138,000 respectively (Karim and Mimura 2008). Along the Southern coast of Myanmar, cyclone Nargis in 2008 caused indentation of more than 50km^2 in the Irrawaddy delta, resulting in an estimated loss of 130,000 to 146,000 lives with economic damages in excess of US$17 billion while in 2011 monsoon rains resulted in a loss of more than US$4 billion when northern and central parts of Thailand flooded (Chan et al. 2012). In December 2014 more than 200,000 people were evacuated when the worst flooding in decades hit Malaysia (The Straits Times 2014) with initial an initial estimated US$270 million in damages (The Malaysian Insider 2015). In a recent report by the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), river-basin floods in the region incurred economic losses of US$16 billion in 2014 alone (Davies 2015). Even at the time of writing Myanmar is experiencing some of the worst flooding in decades with over a million people affected (BBC 2015a).

In Indonesia - where the thesis bases its study on - storm related floods in recent years have inundated 70-80 percent of the city of Jakarta (Fuchs et al. 2011). In 2002, monsoon rains caused floods which left 300,000 people homeless and 30 people dead, while in 2007 the toll rose to 430,000 evacuated and 80 dead (Steinberg 2007). The estimated economic cost quickly stack up, the 2007 flood was estimated to cost US$453 million based on the National Development Planning Agency (BAPPENAS) while the returning floods in January 2013 flood (Fig. 1.1) were reported to cost the city USD$3.2 billion dollars in damages (The Jakarta Globe 2013a).

Fig. 1.1: Photographs taken in Jakarta after a massive flood in 2013. As the frequency and magnitude of these floods increases, so does the pressure on the Indonesian government to find a solution.

While rapid urbanization is often blamed for the environmental degradation and increasing hazards from natural disasters, the magnetic concentration of people, resources and economic activity in cities can also provide for an opportunity to create mitigation strategies that shift the city towards sustainability (Seto et al. 2010). This concentration of resources has allowed for river and wetland restorations to become an increasingly lucrative enterprise with billions of dollars being spent on restoration works (Nakamura et al. 2006). Seen no longer as merely a recreational or decorative exercise, the practice of river restoration can be viewed as an infrastructural investment in which a multitude of benefits can be obtained, inclusive of flood mitigation (Benedict and McMahon 2006).

This thesis attempts to shed some light onto the river rehabilitation strategies which landscape architecture might be able to bring to the table. As a discipline, the theoretical underpinnings of landscape architecture have shifted over the past decades to encompass concepts of “ecological” and “sustainable” design (Swaffield 2002) in which landscape scholars have been encouraged to address a much wider audience and involve themselves in modern day social and environmental issues (Gobster et al. 2010). Concurrently, the profession has been progressively called upon to provide their expertise on the preserving and restoring of wetlands and other environmentally sensitive sites (Hopper 2006). Girot acknowledges this noteworthy endeavor of landscape recovery but challenges practice and discipline to engage with the cultural and environmental dimensions of a site through a combination of physical experience, intuition and scientific research (Girot 1999). Understandably, the complex nature and scale of the problems we face today in megacities such as Jakarta will require a multidisciplinary approach. Landscape architecture is no exception and its desire to encompass ecological considerations has resulted in the discipline bridging into interrelated sciences and adapting new technologies to aid in this respect. The thesis specifically explores one such technological advancement - the advent of reality captured point cloud models of the landscape - and attempts to see how it can be applied as a representative and performative format to assist in finding possible alternative remediation strategies for the ailing Ciliwung River.

1.2 Background

1.2.1 Ciliwung River Background

The area of study, the Ciliwung River, has been at the centre of human settlement in Indonesia since the 4th Century A.D. It is currently the largest and most important of the thirteen rivers, meandering 119km through the cities of Bogor, Depok and Jakarta (the capital of Indonesia) before emptying into Java Sea (Fig 1.2). Unfortunately, increasing urbanisation, commercial development and centuries of exploitation and neglect have transformed the Ciliwung River into one of the most polluted rivers in the world (The Jakarta Globe 2013b). The concurrent anthropogenic factors such as build-up of garbage (Texier 2008) and the rapid subsidence due to groundwater extraction (Chaussard et al. 2013) have also been attributed to the ever increasing seasonal floods in the city. The issue of flooding is further exasperated when municipal infrastructure fails to keep pace with urban growth forcing lower-income communities settled along the downstream section of the river to rely on the polluted river for water, sanitation and even recreation (Vollmer and Grêt-Regamey 2013).

Fig. 1.2: The 119km long Ciliwung River originates on Mount Gede nearly 3000m above sea level and meanders through the cities of Bogor, Depok, and Jakarta before emptying into the Java Sea.

For many centuries, flood management policies in Europe have focused on implementing structural engineering solutions with the original aim of these defenses to allow the system to deal with the floods with the highest probability. Despite of its original intentions, such hard engineering techniques have resulted in an increase in flood exposure and potential social and economic damages (Zevenbergen and Gersonius 2007). The EU water policy has since recognized that floods are a natural reoccurring phenomenon and that a paradigm shift is require to move from a defensive stance into one which embraces and lives with floods ('The EU Floods Directive 2007/60/EC' 2007). The Netherlands has likewise adopted a new "Building with Nature" approach to dealing with costal and river works which leverage off and provides for the dynamics of natural processes (de Vriend et al. 2014). Despite this shift in flood management policies abroad, cities such as Jakarta are still proposing engineered solutions to flood mitigation.

In the past two decades, multiple studies of water management problems and engineering proposals to mitigate flooding have been brought up in Jakarta but none have been successfully implemented (Silver 2014). One of these proposals is the long standing plan to "normalise" the river channel, a project led by the Ministry of Public Works which includes dredging, expansion and bank reinforcement works ('Spatial Planning and Design Details of the Ciliwung from upstream to the Manggarai Dam' 2008) that would change both the topography and land use along the riparian corridor. While these plans were made years ago, the high cost of land acquisition, sensitivity of aggressive demolition and eviction policies, ironically coupled with the allowance for commercial entities to develop along riverbanks and other green spaces (Steinberg 2007), could explain why at present, only a portion of the riparian corridor has been normalised and often only along selected stretches (Fig 1.3).

Riparian vegetation often has to be cleared to make way for piling works.

Concrete piles are driven into the river bed using heavy machinery.

Concrete piles lined up to form continuous walls along the rivers edge.

In certain instances, for reasons unknown, piles were added in addition to already canalised portions of the river.

An example of a "normalised" portion of the Ciliwung River which essentially works like a dyke.

Sediment buildup of a "normalised" portion of the river without routine dredging reduces the capacity of the river.

Fig. 1.3: "Normalisation" or canalisation works occurring along the river often require the removal of existing riparian vegetation to allow heavy machinery to drive concrete piles into the river bed to form a continuous dyke (June 2013).

Like the normalisation project, the two dams along the Ciliwung river, the Ciawi and Sukamahi Dams, which were proposed in 2008 to alleviate the flood downstream have still not materialized 6 years later (Asrianti 2008; Purnamasari and Saudale 2014) and in one of the most controversial project yet, Jakarta's sea wall project which at the cost of USD$40 billion (Ho and Rahadiana 2014) - aimed to ease the annual flooding woes by combating rising sea levels and countering land subsidence - has likewise seen much skepticism (Koch 2015) as well as resistance from politicians, environmentalists and fishermen, causing the project to grind to a halt echoing other previously failed major infrastructural projects in the city (Soeriaatmadja 2015). The social, political and ecological complexity of the current state of the Ciliwung River has thus far resisted any other large scale remediation efforts and the only current immediate action seen to be taken by the administration is to alleviate the flooding situation through the above mentioned normalisation strategy and by dredging 11 rivers and two dams, including the Ciliwung River (The Jakarta Post 2013). Of these measures, the normalisation is still the strategy which currently has the most momentum and residents of who have been residing along some of the worst hit areas live under the constant threat of eviction and relocation to make way for these river improvement works (The Jakarta Post 2015a).

While the situation in Jakarta looks bleak, the fact that most major hard engineering works have been continually postponed allows for the opportunity for alternative options to be brought to the table. It is in the middle of this extremely convoluted problem where the research, positioned within a multi-disciplinary team, has situated itself.

1.2.2 Project Background

The thesis nests itself in the Landscape Ecology Module of the Future Cities Laboratory under the Singapore-ETH Centre for Global Environmental Sustainability. The module's methodology is summarised by a multidisciplinary framework consisting of planners, hydraulic engineers and landscape architects - described in further detail by Vollmer et. al (Vollmer et al. 2015a). It attempts to link riparian landscape changes to human well-being and provide its findings to decision makers in a format which enables involvement from stakeholders. It attempts to do so through an iterative approach which is developed to intertwine mathematical modeling with advanced 3D landscape visualisations that are informed through participatory planning and design methods (Fig 1.4).

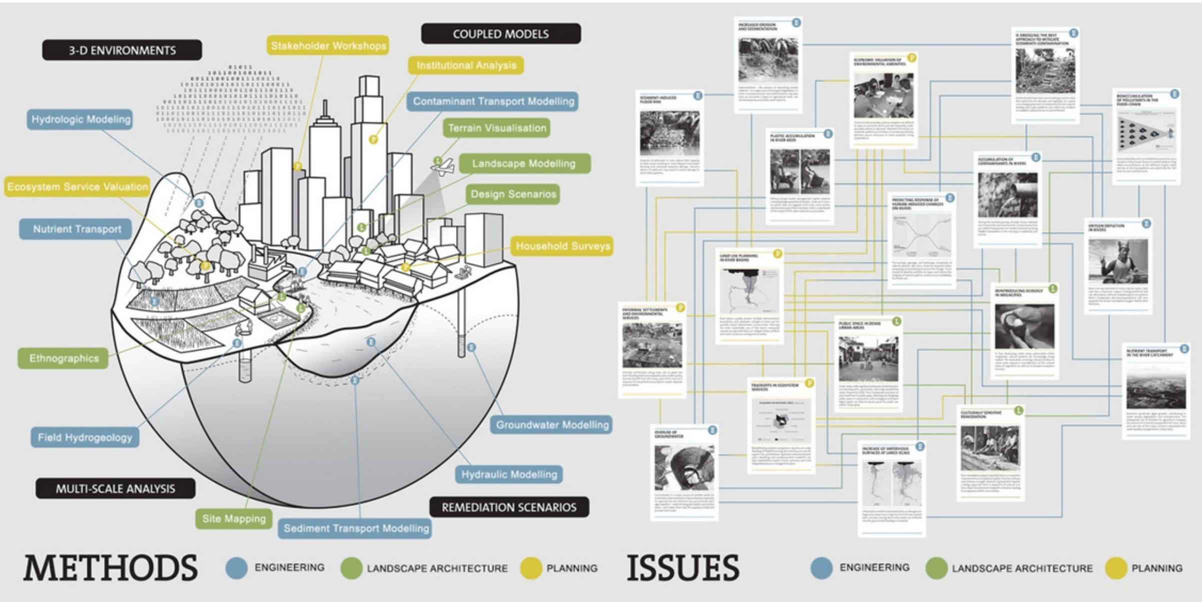


Fig. 1.4: Infographics indicating the three main disciplines (landscape architecture, engineering and planning) in the team coming together to develop methods to resolve a web of interconnected issues relating to the Ciliwung River (Exhibited at the Singapore International Water Week 2012).

The multi-disciplinary research group's eventual goal is to investigate the possibilities of a change in paradigm in river rehabilitation and to provide a future vision balancing the concerns of flooding, water quality and ecology while being grounded in the realities of a megacity such as Jakarta ('Landscape Ecology | Future Cities Laboratory' 2013). This multi-faceted approach was conceived to allow for proposed scenarios to be culturally respectful, ecologically sensitive and yet provide a measure of flood protection and river remediation. We hypothesize three main overarching ideas: firstly, that our integrated modelling approach offers a better way to describe and analyse complex social-ecological systems; secondly that multi-disciplinary approaches to rehabilitation offer advantages over conventional single-sector ones; and lastly that visualisations improve communication of complex information and ideas.

Until recently, flood channel design throughout the world was focused on routing water through as quickly and efficiently as possible. This resulted in smooth trapezoidal concrete conveyance channels which are of little conservation value and require the routine removal of sediment and vegetation in order to maintain their conveyance functions (Greco and Larsen 2014). Alternatively, we believe in the possibility of a restored forested riparian buffer in an urban context, because it represents an area-efficient strategy capable of producing high levels of multiple ecosystem services (Bentrup et al. 2012) and is identified as the best possible location for building the skeleton for an urban landscape network (Cook 1991). Steiner likewise suggests the need to further investigate how green infrastructure systems like river corridors offer the possibility to mitigate the impact of natural disasters (e.g. floods) on human settlements (Steiner 2014).

Indeed the millennium old tradition of planting trees and developing riparian greenways in China begun as a direct reaction to flooding (Yu et al. 2006) and the emergent concept of green infrastructure, could be viewed as the main driver in shaping sustainable urban growth (Yu 2011). Japan similarly has a history of river regulation and flood control owing to the fact that a majority of their population and economic assets lie within the floodplains. These river restoration projects which were originally initiated as a flood defense measure have has since grown to encompass issues of ecology with projects which span across entire corridors (Nakamura et al. 2006). In Singapore, the removal a portion of the concrete Kallang River canal, originally built in the 1970s specifically to address the issue of flooding, has since been replaced with a carefully bioengineered river (Fig. 1.5) to meet not only the original conveyance requirements but also to improve biodiversity and provide for additional recreational spaces (Ng et al. 2011; Baur et al. 2012). Countries from around the world are beginning to see the benefits of such river rehabilitation programs; as such we seek to explore the possibilities of such a river corridor serving as an integrated example of green infrastructure being developed along the entire stretch of the Ciliwung River which plays not only an ecological, social and economic role but also one which has the possibility to mitigate floods.

Fig. 1.5: The Bishan-Ang Mo Kio Park is one of the largest urban parks in Singapore. In 2009, the old concrete canal was demolished and replaced with a bio-engineered meandering river and is now a popular recreational destination for nearby residents (National Parks Board 2015).

To attempt to address this complex approach, the group focuses on three spatial scales namely the catchment, river corridor and site scales (Fig. 1.6) from which a diverse source of techniques and sources were drawn from in order to obtain the necessary base data (Table 1.1). This is done in an attempt to capture the true dynamics of the river and its surroundings as any proposals to rehabilitate the river solely focusing at any one is insufficient due to the fact that river processes span across multiple scales (Schiff et al. 2007). At the catchment scale, the focus is on hydrology and ecosystem services (Vollmer et al. 2013; Remondi et al. 2016) whereby issues of large scale landuse change scenarios are tested and help policy makers to better understand the consequences of different planning strategies. The river corridor scale covers an area of 30km^2 whereby the 40km stretch of the river which meanders through the most flood prone sites in Jakarta. The extent of the river corridor scale was a result of both the limits at which bathymetrical data was available as well as what was believed to be representative enough in terms of space to observe the effects of simulated corridor scale scenarios. At this river corridor scale, mathematical models coupled with 3D terrain modelling and landscape visualisation help predict how changes to the land adjacent to the river may affect the dynamics of the river (Lin et al. 2016). Lastly, three localised sites sampled along the river allow detailed investigations to be carried out to understand the human-environment interactions along the river (Rekittke et al. 2012b, 2013a; Ninsalam and Rekittke 2016; Prescott and Ninsalam 2016; Padawangi et al. 2016). These three sites are seen as samples along the length of the river with the areas of Gadok Katulampa representing the upstream/rural sample, Tanjung Barat representing the midstream/suburban sample and the districts of Kampung Melayu, Kampung Pulo and Bukit Duri representing the downstream/urban sample.

Table 1.1: The three scales of inquiry required a variety of different approaches to obtain the necessary baseline data. The Digital Eleveation Models (DEM) and Digital Surface Models (DSM) for example were obtained from completely different sources. At the catchment scale this was obtained through Shuttle Radar Topography Mission (SRTM) data, at the corridor scale this was obtained through Interferometric Synthetic Aperture Radar (IfSAR) data and at the site scale an Unmmanned Aerial Vehicle (UAV) was used to collect the data. Further information such as air temperature was obtained from the National Oceanic and Atmospheric Administration (NOAA) and solar radiation was obtained from World Radiation Data Center (WRDC) for the catchment scale while bathymetry data used at the corridor scale was obtained from a one-dimensional river model of the Ciliwung developed using the Hydrologic Engineering Centers River Analysis System (HEC-RAS), obtained from the Ministry of Environment.

	Catchment Scale	**Corridor Scale**	**Site Scale**
Area Represented	330km^2 From headwaters at Mount Gede Pangrango to downstream Mangarai Dam	30km^2 From Depok to Kampung Melayu/Bukit Duri Site	5m^2 – 8.5km^2 Upstream Gadok/Katulampa, Midstream Tanjung Barat, Downstream Kampung Melayu/Bukit Duri
Data Sources	DEM from SRTM Precipitation, water levels, terrain and soil properties from Indonesia's Ministry of Public Works and land cover from the State Ministry for Population and Environment Air temperature from NOAA Solar radiation from WRDC	DEM from IFSAR Bathymetry from HEC-RAS	DSM/DEM from a UAV campaign carried out over the 3 sites Bathymetry for Downstream site from Site Survey Close range photogrammetry & terrestrial laser scanning Site Surveys & Fieldwork
Resolution	30m	5m	6mm – 1m
Disciplinary Use	Hydrological Simulations, Planning	Landscape Architecture, Hydraulic Engineering	Landscape Architecture, Social Research

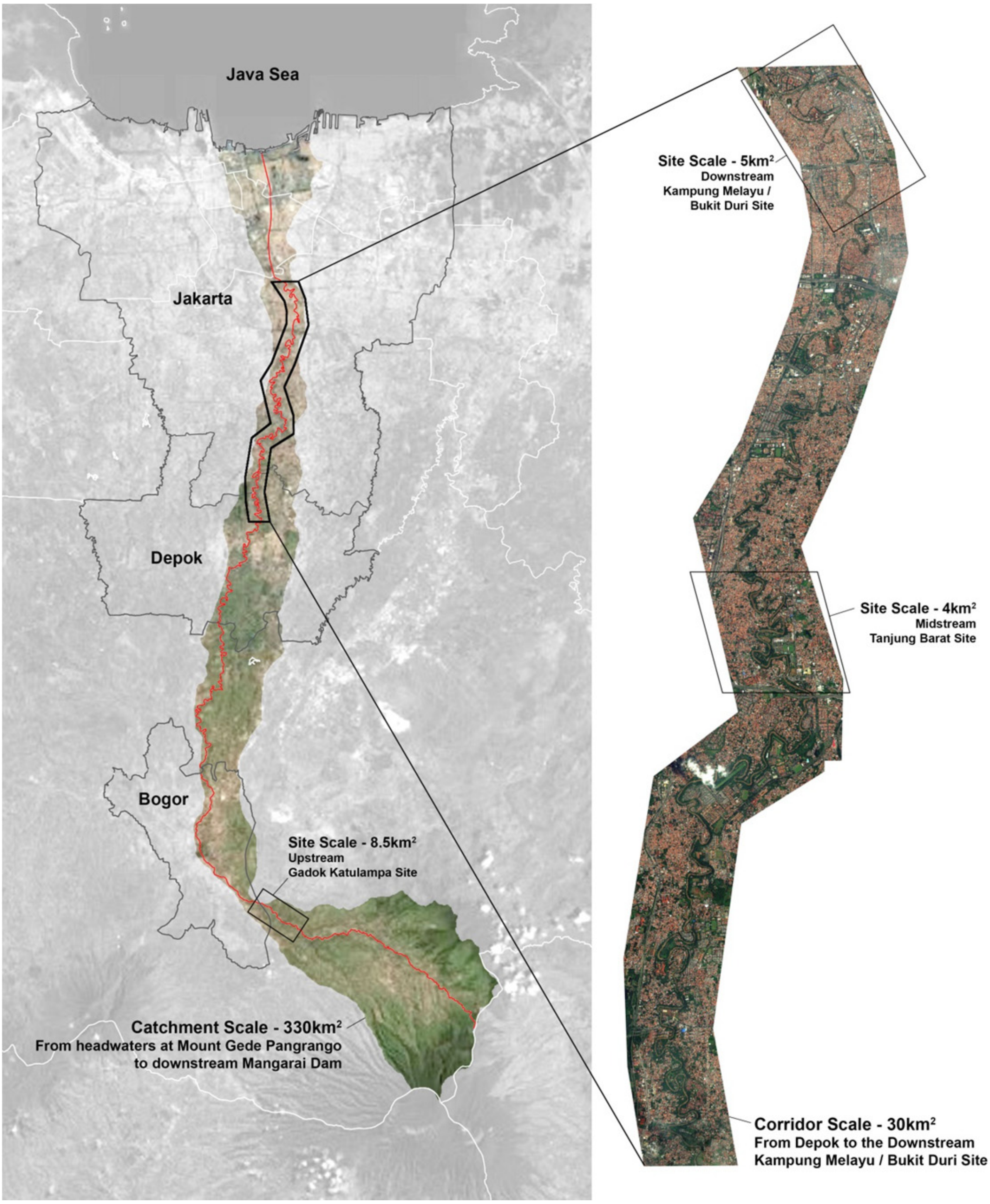


Fig. 1.6: The project is divided into three distinctly different spatial scales, the catchment, river corridor and site scales. Each requiring a different methodological approach but yet all of which are interconnected through the river.

In the years since the project was conceived, a single fundamental issue has plagued its researchers, the lack of or the poor quality of data. With its intention to integrate mathematical models with each other as well as with 3D visualisation models - both data intensive processes - developing countries such as Indonesia prove to be a formidable challenge owing to the sparse, coarse or non-existent data on the topography, landuse, soil structure, vegetative cover, hydrology and socioeconomic indicators. While existing datasets were used as described above, the group had to organize multiple field campaigns in order to acquire additional data which was required by the individual researchers (Fig 1.7). These included hydrological (Shaad 2013; Costa 2013;

Gurusamy 2013), socioeconomic (Vollmer et al. 2015a; Padawangi et al. 2016) as well as local topographic and spatial data (Rekittke et al. 2013a; Ninsalam et al. 2015) at various resolutions across the various scales. These data collection campaigns were often driven by low-cost methods using either simple off the shelf tools or producing them in-house and were assisted through collaborations with local universities and non-governmental organisations. The eventual data collected was geo-referenced and placed within a geographic information system (GIS) framework to be further analysed by the other members of group.

Suspended sediment data collection along the downstream stretch of the Ciliwung River (Gurusamy 2013).

Water quality monitoring and sample collection to uncover the dynamics of contaminant propagation. (Da Costa 2013).

Computer-based household surveys with help from students from the University of Indonesia (Vollmer 2013).

Close range dynamic point cloud capture of the existing environment (Ninsalam 2013).

Boat ride taken down the river to collect videos down the Ciliwung River (Rekittke, Paar & Ninsalam 2012).

Collaborative meetings with local universities and other stakeholders (Lin 2013).

Fig. 1.7: A collection of photographs showing the broad range of field work, surveys and meetings conducted by members of the team in order to obtain relevant data at the scale which was required.

The inherent permeable nature of landscape architecture and its willingness to partake in discussions with neighboring disciplines is one of its greatest strengths (Thompson 2014). The thesis thus focuses on the use of 3D topographical data collected at the site and river corridor scales and attempts to bridge the gaps between the visual representations of proposed scenarios - which landscape architects are often called upon to produce - and mathematical hydrodynamic simulations - which are carried out by the hydraulic engineers in the team. In doing so it is attempting to create feedback loops across the different scales and disciplines (Fig 1.8). In essence allowing the designers to work in unison with the engineers and planners while using visualisations as a powerful way to communicate the findings of the group to support the decision making process (Volk et al. 2009). To do this, the thesis begins by looking at landscape architectural representations as one of the main stepping stones towards this goal of conveying our findings to relevant stakeholders in Jakarta.

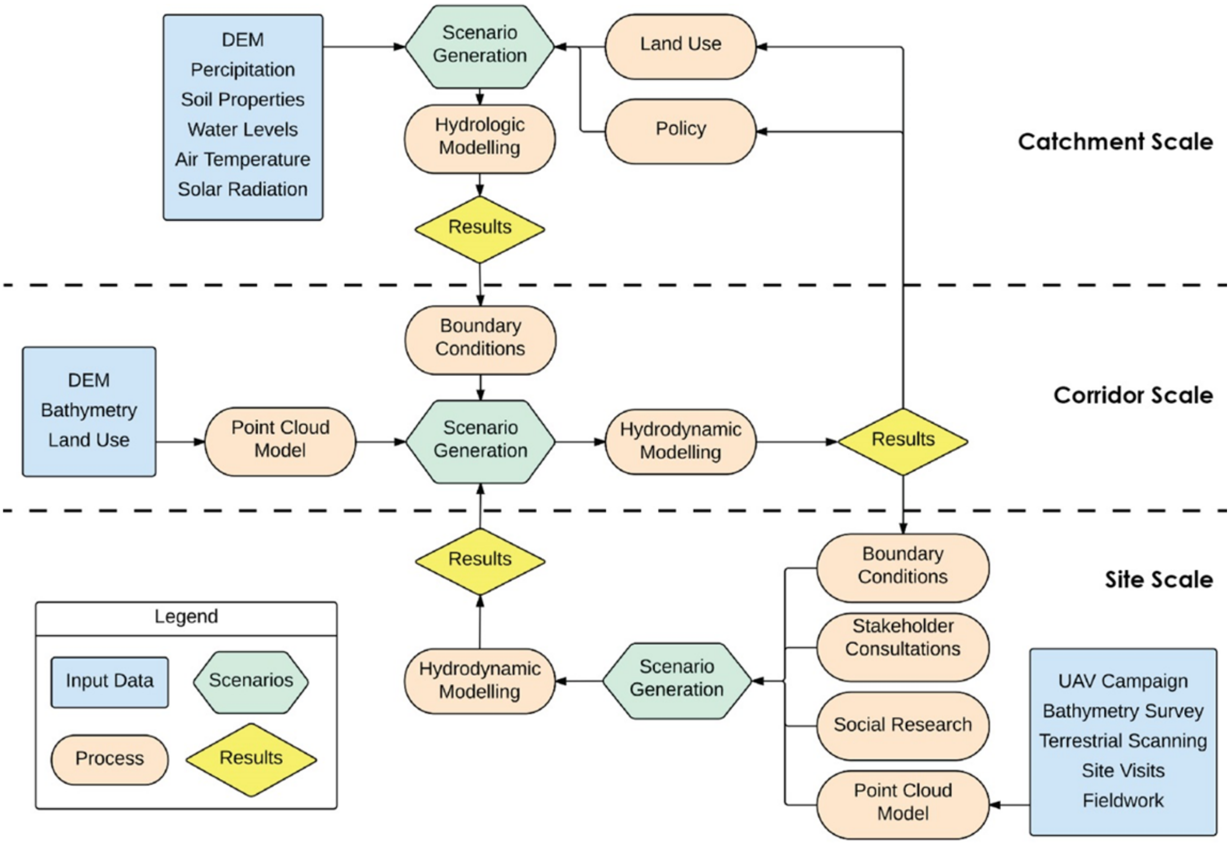


Fig. 1.8: The idea of a complex series of feedback loops and iterations at each interrelated scale was conceived in which both internal and external data and feedback would occur in order to refine the iterations at the identified scales.

1.3 Theoretical Stepping Stones

1.3.1 The Limits of Landscape Architectural Representations

Representations or visualisations have long been a key component of any landscape architectural or planning project (Zube et al. 1987) and the tools needed to visually represent the existing condition of the landscape as well as any proposed alternations to it are essential for designers and planners to communicate their ideas to assist in the decision making process and obtaining the necessary buy-in from stakeholders. With these powerful tools of visualisation in their hands, landscape architects have the capability of changing people's perceptions and motivating actions at various levels (Sheppard et al. 2008) by making the complexity of landscape planning more easily understandable to allow for greater public participation and to support decision making (Steinitz 2008). This has been suggested to be effective with the advent of digital visual simulations as they mimic the human experience of space, time and motion thus making it easily understood and accepted by members of the public (Kwartler 2005). Even the creation of an image of a proposed intervention alone instills viewers to question and think about the proposal itself (Meitner et al. 2005).

The visual representation of landscapes has a long history and the two, landscape and image, are inseparable (Corner 1999a). During this long history, landscapes have been considered the product of ideal representations of the world captured within a picture frame (Girot 2013). From Roman frescoes depicting idealised landscapes, to the development of the perspective during the Renaissance, to the carefully framed representations of seventeenth-century Dutch landschap paintings, to the advent of photography, centuries of scenic imaging have resulted in an idealised understanding of the landscape. The Picturesque movement for example, while developed from a reaction towards urbanisation and modernization, conjures up imagery not known by its formal attributes but by the feelings it evokes (Meyer 2002), became so prevalent that the taste for Picturesque scenery still persists today (Thompson 2014).

In landscape gardening (the precursor to landscape architecture), Humphry Repton (1752-1818) pioneered visualisations applied to design issues for his clients (Lange and Bishop 2005). Departing from the imposed landscapes from advocates of the Picturesque movement, his famous Red Books consisted of a flap which would allow his clients to alternate between the original and proposed watercolour illustrations showing the changes made to the landscape and thus attempting to evoke a positive response in the viewer (Fig. 1.9). The idea of contrasting present and proposed scenes is a tradition that has trickled down to contemporary landscape architects. Unfortunately, one might still argue that the critique of Repton's strategy being an advertising technique equivalent to that of a conman (Daniels 2008), still holds water today when put into the context of the modern profession. Such continual representations of idealised objectified landscapes run the risk of designers making "pictures" not "landscapes" (Corner 1992a) and will only serve to limit the full scope of creative thinking of the landscape (Corner 1999a).

Fig. 1.9: Water at Wentworth, Yorkshire, before (left) and after (right) where proposed changes to the landscape are compared by a lifting a flap to alternate between the two (Repton 1803).

Yet it is difficult to fault landscape architects, for in practice, they require representations which are simultaneously abstract and simplified, yet legible and communicative while reacting to the need to communicate ideas to the client for a project to be realised (Andersson 2008). This need to visually communicate ideas has manifested itself through a multitude of techniques such as orthographic plans, sections and elevations (Reid 2002); construction drawings (Hopper 2006); hand drawn illustrations (Hutchison 2011); digital collages (Cantrell and Michaels 2010a); explorative mixtures of analogue and digital techniques used in the teaching of landscape architecture (Amoroso 2012a); all the way to advanced image modifications, animations, parametric, augmented, virtual landscapes used by academics and professionals (Amoroso and Hargreaves 2012). These landscape representations exist in different forms throughout the design process, from observational drawings to mapping, design sketches to physical models and construction drawings to final rendered perspectives (Entwhistle and Knighton 2013a). Often these different types of representations are seldom seen in isolation but are rather displayed simultaneously in order to provide a comprehensive overview of the project (Fig. 1.10).

Fig. 1.10: A range of representations are often used in conjunction, here photographs, maps, plans, rendered perspectives as well as augmented physical models used to communicate to a wider audience (Exhibited at the 2014 International Architecture Biennale Rotterdam).

In academia, landscape visualisations are widely adopted for use in the visual assessments of large-scale projects, for simulating changes to the landscape and for other research purposes (Paar 2006). Unfortunately, while the complexity and quality of landscape representations have vastly improved with the advancements in visualisation technology (Danahy 2001), the debate continues to argue for the linking of representations to thinking rather than the mere creation of special effects (Treib 2008a) and understanding how best to use them in practical planning applications (Lovett et al. 2015). These improvements in visualisation technology have not grown in tandem with the knowledge of how to effectively use them in communicating with multiple stakeholders (Pettit et al. 2011) and as a result there has been a call for landscape visualisations to achieve higher levels of credibility, legitimacy and saliency (Table 1.2). Even before the influx of modern day landscape visualisations, Sheppard suggested a code of ethics which could help provide scientific validity to visualised landscapes in order for them to be defensible (Sheppard 2001) and understood the power of visualisations and the responsibility the preparer bears (Sheppard and Salter 2004). To achieve this, landscape visualisations need to move beyond the physically perceivable environment to link with numerical models which simulate real world dynamics (Lange 2011) to create scientific visualisations and projections that act as a means to communicate and analyse complex relationships between the inhabitants and their environment (Mitasova et al. 2012). This merger of scientific rigor with landscape modelling are more likely to form credible visualisations (Lange and Bishop 2005) that allows for honest communication through their transparent production and presentation (Downes and Lange 2015) and will eventually allow for better communication and gathering of support from stakeholders.

Table 1.2: Overview of the three criteria which can be used to evaluate landscape visualisations when communicating with stakeholders (Lovett et al. 2015).

Criteria	Description
Credibility	Refers to the scientific underpinnings of a visualisation which consequently allow the viewer to believe that the real landscape is adequately represented.
Legitmacy	Refers to the understanding that the visualisation is produced in an unbiased and fair manner.
Saliency	Refers to the need to have the concerns of stakeholders addressed in the visualisation

1.3.2 The McHargian Legacy

This desire to form credible visualisations is made possible with the adoption of sciences into the landscape architectural discipline. Perhaps the single most influential science for landscape architecture is the study of ecology. In its decades of development, the study of ecology has provided the scientific foundation for understanding natural processes, managing environmental resources and achieving sustainable development in the planning and design for human use. Ian McHarg went so far as to suggest that the adoption of ecology offers "emancipation to landscape architecture" by allowing landscape architects to act as bridge between the natural sciences, planning and design thereby liberating them from the stigma of being classified as ornamental horticulturists or merely an afterthought to architecture (McHarg 1967). In his lectures and publications including his highly influential book Design with Nature 1969 (McHarg 1969), McHarg details his method of map overlays which provided the framework to store, process or present large amounts of spatial data (Fig 1.11). Each of these overlays represented a single source of information which would influence the eventual landscape design including ecology, hydrology and geology. Such techniques of collating and interpreting ecological processes through a series of abstracted 2D base maps has since been digitised as the needs and demands for very large spatial databases grew in unison with the tools and technology available to handle them (Dangermond 1988). The resultant GIS software platforms and techniques have been handed down and inherited by the landscape architects and planners of today.

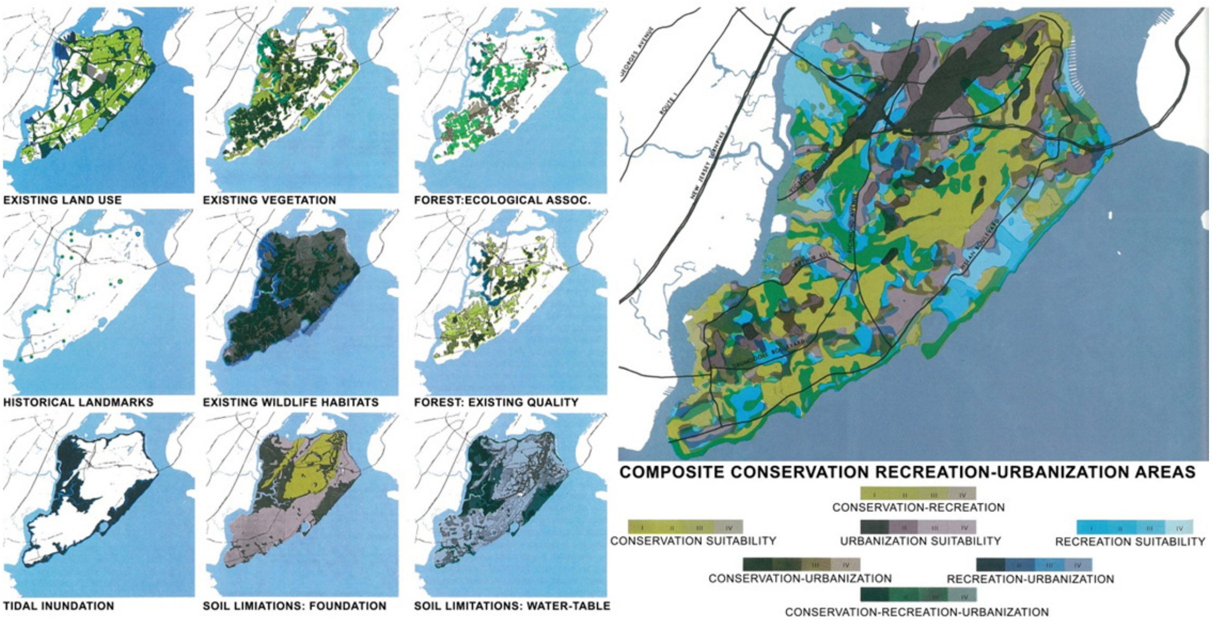


Fig. 1.11: An example of McHargs overlay techniques in which a series of maps of different processes are overlaid to form a final composite to inform of the development of Staten Island (McHarg 1969).

A more recent, and perhaps relevant to this thesis, branch of modern ecology is that of landscape ecology whose inception was the result of attempts to bridge the spatial-chronological approach of geography with the functional and spatial approach of ecologists. Its holistic approach in reconciling the role of humans in the landscape and the systematic and unbiased study of the subsequent ecological implications have also attracted foresters, agronomists, gardeners, planners and landscape architects (Makhzoumi 2000) to its calling. For landscape architects, Dramstad et al. provide a pictorial representation of the landscape ecological principles (Dramstad et al. 1996) which echoes ideas derived from the classical theory of island biogeography in which particular spatial arrangements are theorized to be better than others owing to their size, fragmentation, connectivity or shape (Fig. 1.12).

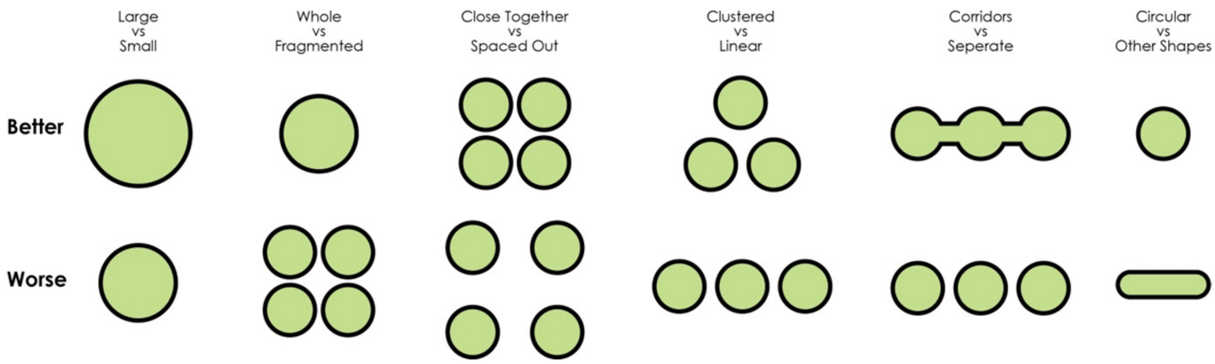


Fig. 1.12: Diagrammatic guiding principles for the design of natural reserves for which in all six cases, species extinction rates will be lower (better) for the designs on the top row (adapted from Diamond 1975).

Naveh and Lieberman also outline several main areas for further development of landscape ecology (Naveh and Lieberman 1994b). Firstly, the development and application of integrative and quantitative methods and models to better understand the complex relations between man and nature on a landscape scale. Secondly, to continue to involve and integrated ideas and expertise from other fields of science in order to further ground itself as a transdisciplinary and problem solving science. Lastly, to find more effective ways of communicating findings to persuade land managers, users, decision makers and members of the public to choose alternatives which are focused on environmental management.

One such development to incorporate quantitative methods and models into landscape ecology is the development of landscape metrics. Landscape ecology is largely based on the idea that environmental patterns influence ecological processes (Turner 1989) and these patterns are often quantified using landscape metrics (Uuemaa et al. 2013a). The patch-matrix-corridor (PPM) model (Forman 1995) can be regarded as one of the first descriptive and conceptual models for landscape structures in landscape ecology (Lausch et al. 2015) and these underlying landscape structures serve as a key indicator of how the land works for people and for nature (Leitao et al. 2006). While it is currently being debated that the initial interest in the PMM has given way to skepticism and critique (Lausch et al. 2015), considering its simple and practical implementation and the simplicity and speed of calculation landscape metrics (Uuemaa et al. 2013), a portion of the thesis will thus attempt to use such metrics to measure the landscape structural changes to attempt to find a correlation with the flood simulations (Chapter 4.3.6).

Although technological developments have allowed for GIS practitioners and landscape ecologists to move away from a more descriptive approach to one which is prescriptive and anticipatory (Naveh and Lieberman 1994b), GIS and traditional sciences are still predominantly reductionistic when compared to design sciences which focus on synthesis (Couclelis 2009). The rigidity of tools and methods developed around the GIS platforms makes it excruciatingly difficult to quickly generate new design proposals (Tomlin 2012), coupled with its severe analytical rigidity and disconnect with human intent (Toms 2010), are probably why the uptake of GIS by practicing landscape architects falls far behind (Hanna and Culpepper 1998).

In comparison to the ecological sciences, the practice of Geodesign is more explicit in its desire to manipulate the environment in order to achieve its goals, perhaps owing to the typical differences in scales in which the design and geographical science professions operate (Fig. 1.13). Steinitz defines Geodesign as the development and application of design related processes intended to change the geographical study areas in which they are applied and realized, or to put it simply Geodesign changes geography by design (Steinitz 2012a). While its exact definition might eventually evolve into something else altogether (Ervin 2012a), the literature on Geodesign seems to point towards several overarching trends which were influenced by the legacy of Ian McHarg. Geodesign takes an interventionist stand by adopting applied science and engineering methods to solve real world practical problems (Goodchild 2010). It seeks to achieve this by harnessing the growing power of modern technologies and coupling them with the traditional practice of planning, designing, implementing and evaluating alternative future scenarios of our environment (Ervin 2012b). This notion of generating, recording and evaluating alternatives provides a platform for which decisions can be made (Tomlin 2012) and has to be supported by a collaborative effort with an emphasis on visual communication (Schwarz-v. Raumer and Stokman 2012). The process becomes particularly pertinent when dealing with larger projects as the scientific complexity increases when the size of the project increases (Steinitz 2012b).

Fig. 1.13: As the scale of a project changes, typically so does the related disciplines which operate at these scales and associated strategies and approaches they bring to the table. As the size of projects get smaller, the focus leans towards more "offensive" strategies which are a synthesis of localized factors preferring to prescribe the "look and feel" or the expression of the project. In contrast as the scale of the project goes up, "defensive" strategies are adopted with a preference towards analyzing and describing that which is on the ground in order to allocate the use of land (adapted from Steinitz 2012a).

In summary, with an appropriate use of technology, the Geodesign process allows for the integration of site data to create, design, visualise, assess, compare and evaluate urban and landscape planning projects that are backed with scientific evidence. Its successful application in practice can coexist with existing workflows and improve overall project efficiency by allowing for effective communication of proposals to various stakeholders, thus allowing for the "buy-in" required which reduces the cost of delays (Biggs 2015). Similar to the science of landscape ecology, the practice of Geodesign also seeks to collaborate with other disciplines, to couple quantitative analysis into assessing future scenarios and to develop ways to communicate the eventual findings effectively and as such will be a framework in which the thesis takes reference from during its course.

1.3.4 The Converging of Visualisation and Testing

The practice of integrating quantitative analysis in the realm of design and planning has been spurred on by concerns of sustainability and environmental consciousness. In architecture, the need to assess a buildings performance prior to its construction has led to the multi-disciplinary field of building performance simulation (BPS). BPS gathers professionals from diverse fields of design, physics, mathematics, material, environmental and computational sciences to predict a buildings energy consumption requirement. While BPS was often used just prior to construction for validity purposes (Flager and Haymaker 2009), there has been a push for it to be adopted in the early stages of design instead (Schlueter and Thesseling 2009; Attia et al. 2012; Negendahl 2015). By introducing the BPS process in the initial phases of a buildings conception, it should assist architects by narrowing down on the permutations and combinations which are the most efficient right from the onset of the project.

Similarly in landscape planning, Environmental Impact Assessment (EIA) studies serve as a systematic, anticipatory and participatory process of considering all possible impacts prior to the implementation of any major project that has the potential to significantly affect the environment. A related procedure called Landscape and Visual Impact Assessment (LVIA) is usually carried out by landscape architects. While EIA deals with measureable, technical or otherwise quantitative judgments, LVIA focuses on qualitative ones which are typically more difficult to assess (Institute and I.E.M.A 2013) and often requires the use of visualisations during the process (Fig. 1.14). Although implemented in many countries around the world, EIA's poor integration within the decision making processes has caused it to have limited influence in consent and design decisions (Cashmore et al. 2004) and has been seen to have fallen short of its full potential (Jay et al. 2007).

Fig. 1.14: Visualisations such as these and a corresponding survey are an essential parameters for evaluating public acceptance prior to the building of wind farms (Betakova et al. 2015).

Just as it is an extremely complex task to fully model and predict all aspects of a buildings performance, the analysis of a landscape plan or design is an equally, if not much more, complicated task. A more recently developed framework by the Landscape Architecture Foundation (LAF) is that of “Landscape Performance” (LP) which is defined as “a measure of the efficiency with which landscape solutions fulfill their intended purpose and contribute towards sustainability” (Landscape Architecture Foundation 2010). LP was created following other established performance rating systems originally developed as a performance-based green rating system for the design, construction, maintenance and operation of buildings and sites, such as the Leadership in Energy and Environmental Design (LEED), the extended LEED for Neighborhood Development (LEED-ND) and the Sustainable Sites Initiative (SITES) (Ndubisi et al. 2015). Unlike LEED-ND and SITES which are carried out at the design and early construction phases, LP attempts to measure real life performance after landscape projects are built and occupied and as such are often discussed using a case study approach (Luo and Li 2015; Ozdil and M. Steward 2015). Ndubisi et al. go on highlighting that while there has been an increasing need for landscape architects to provide credible evidence to support, guide and evaluate the outcomes of design decisions, designers lack the resources and abilities to evaluate the performance of their projects and this difficulty in representing the value of landscape solutions often results in them becoming marginalized as decoration. LP is thus emerging as a way for designers to append a value to their designs based a comparison against established baselines or norms. The Landscape Performance Series (LPS) Benefits Toolkit was developed by the LAF specifically to help in this matter and consists of a searchable collection of online tools and calculators which can be used to estimate specific landscape benefits for completed projects or applied during the design phase to compare projected benefits among different alternative scenarios ('Benefits Toolkit' 2015).

However, a critique for these performance testing or rating procedures is pointed towards the fact that they are either poorly integrated or introduced only after the design process has taken place. In BPS, it has been found that this is a result of the tools and methods used in early design stages being inefficient in providing a platform that delivers feedback from rapidly changing design alternatives (Negendahl 2015) and while the LPS Benefits Toolkit is a step forward, it is still very much in its infancy and still requires a fair amount of user intervention to obtain results.

Similar to the role simulations and ratings play in the early design stage decision making process, the science of instream flow assessments aims to assess the trade-offs and impacts of any specified river management strategies (Pasternack 2011) and is one area that can benefit from the integration of early stage design scenarios which are refined through the quantitative analysis provided by numerical modelling of river hydraulics (hydrodynamic modelling). This idea of using the underlying dynamics of a hydrologic system as the initial design and planning driver is hardly novel to the field. McHarg has already demonstrated this by employing a meticulous technique of gathering and overlaying pieces of data to reveal the workings of the Potomac River Basin (McHarg 1969). These underlying hydraulic or hydrological systems and the landscape relations they create can play a key role in allocating land use to the landscape (Ndubisi 2002). In reverse, changes in land use and topography along the riparian landscape will likewise affect these hydraulic and hydrological systems, especially so in a river such as the Ciliwung whereby urban settlement has made its way right up to the banks of the river. Any potential change to the riparian corridor along the river will thus need to be a calculated move as it would have a multitude of consequences.

Considering how the issue of flooding is such a major issue in Jakarta, the main evaluative component to be expanded in this thesis will be the hydraulic performance of the river resulting from the alternative scenarios proposed. The results from such simulations would play a significant role in the selection and implementation of urban flood management strategies but are unfortunately hindered by complexity of obtaining, managing, and analysing different datasets required to run such simulations using GIS programs (Oberle and Merkel 2007). In addition, the results of these hydrodynamic assessments are often statistical in nature and difficult for designers and stakeholders to interpret, thus leading to a call for them to be visualised in order to create a powerful tool which enables a common language from which multiple parties can participate in the decision-making process in the context of flood risk management (Burch et al. 2010). When they are produced specifically for consumption by stakeholders - such as water management authorities, municipalities, civil protection agencies and the general public as well – visualisations indicating factors such as flood hazard, risk or probability maps (Fig. 1.15) are the most common visual tool of communication (Spachinger et al. 2008).

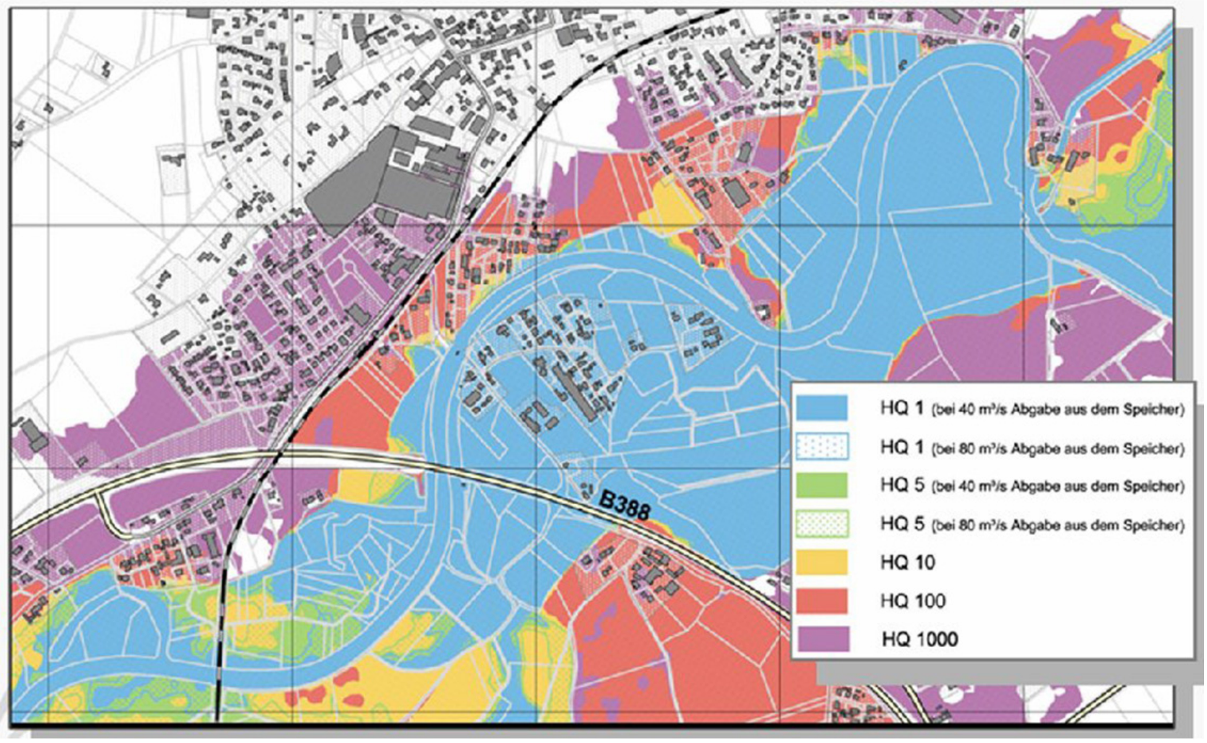


Fig. 1.15: Flood probability maps such as this are a common and easily understandable form of visualisation to assess the extent and impact of hydrological events and to subsequently communicate flood risk to different target groups (Spachinger et al. 2008).

Within both academia and practice, landscape representations have slowly begun shifting from a romanticized picture to one which seeks to investigate landscape performance (Hood 2012). The desire to visualise the results of hydrodynamic simulations to serve as a tool for water and calamity management as well as urban planning has already begun to spawn powerful integrated solutions (Stelling 2012; 3Di 2015). It is evident that the knowledge and tools behind the mechanisms of urban flood formation and the availability of mathematical models has improved significantly and what is required now is a more efficient way to develop and test new scenarios by providing better user interfaces as well as to adopt new technologies of remote sensing (Pasche 2007). In light of this, an initial component of the thesis will focus on developing the necessary tools and methods to work with point cloud models which integrate design outputs and quantitative numerical models to produce visualisations that are founded on scientific simulations. In doing so, it is anticipated that the proposed scenarios can be evaluated in an iterative loop to find the best possible proposed one which is able to balance concerns of flooding, ecosystem services and the recreational and scenic potential of a river.

1.3.5 The Emergence of Point Clouds

Architects have historically used physical models to study the complex three-dimensionality of their designs. Landscape architects in contrast have traditionally used maps and plans to represent their proposals as it was generally perceived that the plans alone were sufficient enough to represent the spatial relationships within their proposals, which are often more horizontal than vertical in nature (Walker 2008). This is probably due to the fact that landscapes are almost always open to the sky and as such landforms, grading and plant layout represented in a plan are easier to read as compared to that of a building, but the practice of designing landscapes through the use of a formal plan was something which McHarg disapproved of, preferring to base his designs through an interpretation of ecological processes represented in the form of maps (Treib 2008b). Long associated with planning and design, maps have the potential to uncover hidden truths previously unnoticed or unseen and can serve as the starting point for further discourse (Fig 1.16) where the process of mapping is used not merely as a reproductive medium but a creative one (Corner 1999b).

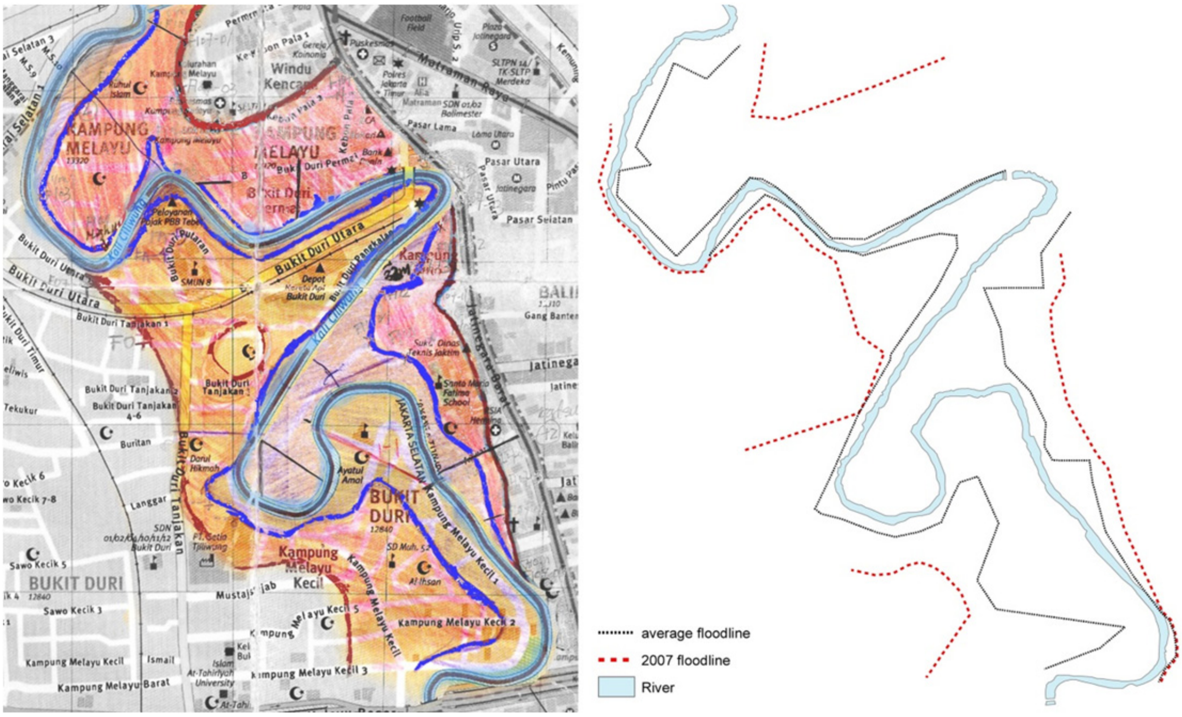


Fig. 1.16: One of the first maps to be generated of the downstream site was generated by hand, drawn over a street map of the area and eventually digitised indicating the estimated flood extent through interviews with residents in the area. Before the availability of UAV data and the associated flood simulations, students used this map to inform their design scenarios (Rekittke et al. 2012a) (described more in detail in chapter 4.2.1).

The techniques to produce maps have come a long way since the time of Mcharg, yet because the process of mapping is inherently one of abstraction or generalization by the creator of the map. Being based on the information required by the study's parameters, maps are fundamentally biased and planners often have to resort back to aerial photographs to provide important spatial characteristic information which would otherwise be obscured in maps (Danahy 1997). This reliance on aerial photography till this day has produced a distinctly overhead perception of our landscape which differs from the original sequential terrestrial views and has since shifted the idea of landscape from a scenic pictorial exercise to one which is best coordinated from above (Waldheim 1999). The aerial perspective has been described to have replaced typical orthographic representations as the primary method of landscape design expression owing to the rise of available technology and its capability of conveying the spatial qualities of landscapes (Fletcher 2014). This eye in the sky approach is no longer purely image making in the form of photographs (Fig 1.17) but has simultaneously developed into remote sensing techniques which serve as a tool for holistic landscape evaluation as a result of its powerful ability to survey the land (Naveh and Lieberman 1994a). Remote sensing is defined simply as the acquisition of knowledge or data by unattached means, this acquisition can occur through the use of aerial photography, satellite imagery, radar and thermal imagery. Such techniques can now shed light on the physical and even chemical makeup of our environment and has found a place in a multitude fields such as forestry (Packalén et al. 2008; Leeuwen and Nieuwenhuis 2010), conservation (Nagendra et al. 2013), GIS (Bishop 2013) and urban building and land classification (Lu et al. 2014; Yan et al. 2015).

Fig. 1.17: Oblique aerial photographs provide a vantage point over the river which is otherwise impossible to observe and allow for a better understanding of the spatial qualities of the landscape.

However, regardless of the form of top-down representation - maps, plans or aerial photographs – they are all inherently two dimensional in nature. In contrast to these two dimensional abstractions of existing conditions, which tend to flatten and oversimplify nuances of a physical landscape reality (Girot 2013), we now seek to leverage on the spatial information provided by three-dimensional models. This is important as there is a need to begin shifting from a traditional 2D mode of inquiry into a 3D one - considering how the real world is exists in three-dimensions (Lange 2001). This shift towards a three dimensional mode of operation will certainly be powered by emerging technologies.

The practice and research of landscape and urban planning have adopted technological advancements in computer aided design (CAD) by producing realistic visualisations of our landscapes to communicate to stakeholders and the general public. In the past decade, such improvements mean that three and four dimensional representations have become common place in this process. Traditionally the building of such 3D models required the landscape architect to begin with the acquisition of raw geospatial data, processing them into an appropriate format and lastly using them as inputs into software which will construct the final geometry (Lange and Bishop 2005). The manual combination of these data sources allows for the virtual representation of the terrain, vegetation, animals and humans, water, built structures as well as atmosphere and light, the most important variables which determine the visual appearance of a landscape (Ervin 2001). As opposed to this manual method of building up the base model from scratch, the science and technology behind remote sensing have become more accessible than ever before and now allow for the collection and processing of our world directly into georeferenced 3D digital data (Richter and Döllner 2014). Emerging reality capture based remote sensing technologies such as unmanned air vehicles (UAV) fitted with various sensors and Light Detection and Ranging (LiDAR) devices allow for incredibly detailed digitized models of the landscape (Fig 1.18) to be obtained directly from reality, thereby inversing the traditional workflow of obtaining digital models through manual means (Ervin 2003).

Fig. 1.18: 3D models generated from aerial and ground photogrammetry, allow for fully textured, geographically accurate and high-resolution 3D models which include all natural and man-made objects present in the landscape at the point of data capture without the need for manual modelling (Pictures courtesy of AEROmetrex/Aero3Dpro - AEROmetrex 2012).

One of the main outputs of these new remote sensing tools are three dimensional point cloud models of the landscape which represent a digital collection of geographically positioned three-dimensional coordinates, or points, that can have additional metadata associated with each point (White 2013). After collection and processing, the resultant digitised model represents an object, space or event manifested in the form of a full colour point cloud 3D model that once stored can be digitally revisited repeatedly – a digital replica of reality, no longer landscapes but "scanscapes" (Shaw and Trossel 2014). The ability for a UAV to cover vast areas and the 3 dimensional point cloud model it generates makes it particularly suitable for dealing with the lack of reliable data from areas such as along the Ciliwung River, allowing us to obtain a precise and unbiased 3D model of the riparian corridor without needing traditional surveys to obtain topographical maps (Fig 1.19).

Fig. 1.19: Images taken from a UAV flown over the downstream Kampung Melayu, Bukit Duri site were processed into a 3D point cloud model to allow researchers to further their work on the site (described further in chapter 3.2).

While these technologies are under a constant state of improvement, the application potential of reality based datasets has many prospects which need to be explored (Gruen 2009). These new developments have already shown great promise in the fields of archaeological research (Tapete et al. 2013), cultural heritage management (Nettley et al. 2012; White 2013), visual impact analysis (Czyńska 2015) and forestry (Leeuwen and Nieuwenhuis 2010). Flood management and flood simulations likewise have also benefited from the utilization of reality captured point clouds (Abdullah et al. 2013; Santos and Freire 2013; Kehl and Haan 2013; Meesuk et al. 2015). Unfortunately the majority of architectural ideas developed with digital technologies have still remained conservative, preferring to stick to historical practices (Amoroso and Hargreaves 2012). Landscape architects in particular have failed to adopt the computational design practices which architects have been experimenting with since the 1960s. In the same way which architects use computers to simulate structural, solar and thermal performance of their buildings, landscape architects should do the same for hydrological, ecological and other landscape related criteria (Belesky 2013).

This failure to adopt such technological developments could possibly be compounded by the fact that the tools and methods that are available are more akin to engineering than design, which again leads to the need to develop them to enable the adoption of a point cloud workflow. In addition, with all its accuracy and as ground breaking as these new digitizing methods and their resultant point cloud models are, they still are only able to provide the as-is state of the landscape. This thesis aims to go beyond this descriptive as-is state to one which is prescriptive which allows for proposed scenarios to be represented within an existing point cloud dataset. Here, the medium of the point cloud model serves as the starting point for informed design choices enabling precise interventions to be embedded into the digitised landscape which are then further tested for their performative potentials.

With the 3D model being created even before the creative process begins, the question of what influences this shift in paradigm will have on the products of landscape architecture needs to be discussed (Dooren 2008). Perhaps this can finally allow us to free ourselves of this overly simplified 2 dimensional trap into an imaging activity that generates creative thinking (Corner 1999a) and offer a return to the physical realities of a site to learn of its character, potential and inherent qualities (Girot 2013). Consequently, with the starting point reverted to a model first before an image, the model itself with all its intricate details becomes, as Girot puts it, the generative force for design, eventually allowing us to begin questioning the traditional formats of landscape representations and the possibilities which come along with adopting such a workflow.

1.4 Problem Statement

Prior to understanding how the use of point clouds influences landscape architecture, we first need to be able to work with the data effectively. The preliminary issue thus is the lack of a suitable software platform and tools required to handle point cloud models. Reality captured 3D point cloud models serve as a credible source of data collected from the landscape, unfortunately while there are a growing number of software platforms (such as those from from Autodesk and Bentley) which allow for the visualization, registering, tracing and manipulation of point cloud data, the creation of new point clouds and the ability to inject scenarios into them requires the creation of custom tools specific to this need. This lack of a suitable software platform is of course far from being a new problem as when it comes to visualisations, GIS, Geodesign, hydrodynamic simulations or landscape ecology, there simply is no one single software platform or tool which is able to encompass the multitude of requirements from each related discipline let alone be able to bridge across them.

In addition, the point cloud models collected from UAVs through photogrammetry are often not encoded with addition semantic information (Fig 1.20) unlike LiDAR data which can be used to identify urban land use, detect vegetation and otherwise segment the data into distinct classifications or objects (Yan et al. 2015; Zhou and Neumann 2013; Höfle et al. 2012; Lu et al. 2014; Brodu and Lague 2012). This semantic information (e.g. land use classification information), if embedded in the individual points of a point cloud, enables for more effective processing, analysis and visualisation (Richter and Döllner 2014) and provides for the possibility to interface with numerical models and begin the process of working within an interdisciplinary environment.

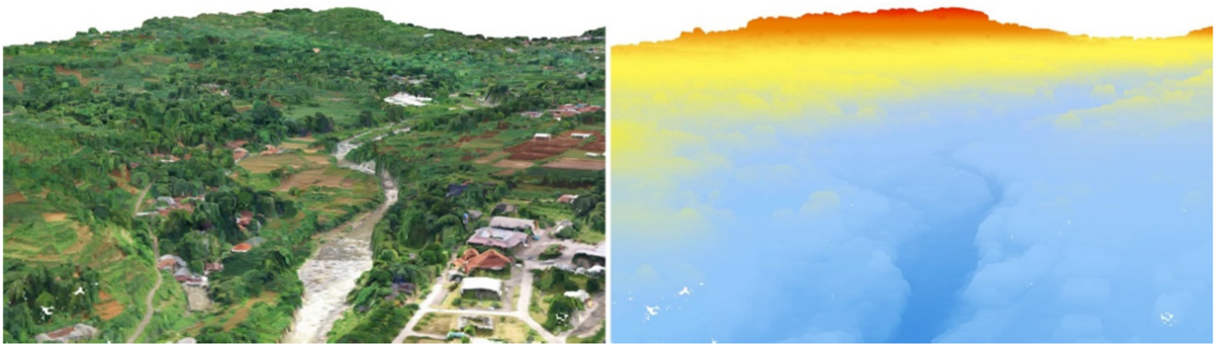


Fig. 1.20: Point cloud models obtained from UAV sources often contain only colour information (left) and elevation information (right), objects such as buildings, vegetative cover, water surfaces and any other semantic information are often not embedded into the point cloud data.

The multitude of technical difficulties surrounding the collection, storage, manipulation and testing of reality captured 3D point cloud models has resulted in an absence of work being done in this regard by landscape architects and planners. Some headway has already been made (Fricker et al. 2012b; Joye 2013; Oehlke et al. 2015) but the discipline in general has not caught up to speed with these developments. This void in the tools to work with point cloud models has resulted in a lack in explorations into the underlying benefits, potentials, pitfalls or consequences of adopting point clouds into landscape architecture. The thesis thus attempts to resolve this issue of developing the tools necessary to explore how point clouds can be adopted into landscape architectural workflows and the potential benefits and challenges uncovered in the process of exploring possible solutions for the Ciliwung River.

1.5 Aims and Objectives

1.5.1 Hypothesis

The thesis hypothesizes that the point cloud model can serve not only as an effective format for representing landscape architectural projects but also simultaneously provides a platform from which an interface with quantitative performance testing models can be made possible. This integration with numerical models exists within the same point cloud environment allowing for a more streamlined approach to representing and testing different designed scenarios. This differs from the current norm whereby representative and performative models exist in completely different environments and require a separate workflow for each (Fig 1.21).

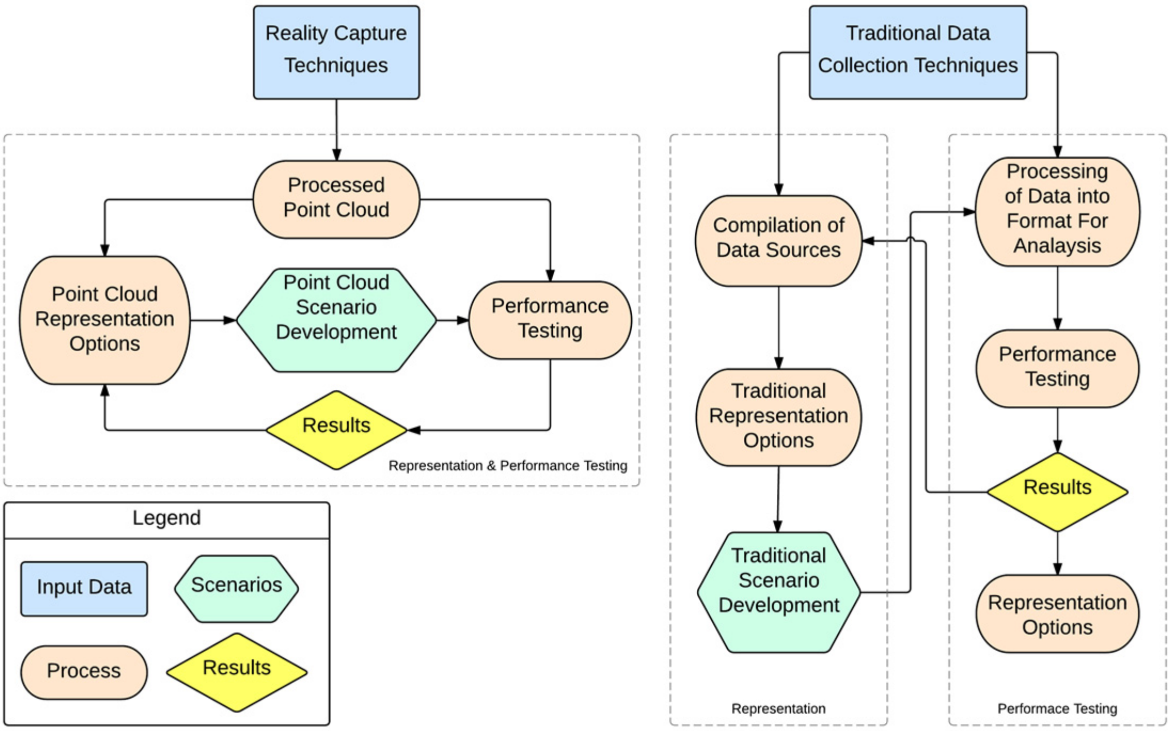


Fig. 1.21: Unlike how representation and performance testing workflows are completely separate and require the need for additional steps to traverse between one and the other, the thesis proposes that point cloud data form the base in which both representation and performative testing exist within the same workflow and software environment.

In order to test this hypothesis, several interrelated aims and objectives must be attained to understand the challenges, opportunities and differences when adopting a point cloud based workflow. In summary, these aims and objectives include:

- Developing a set of tools and workflows in order to work with existing point cloud data.
- Comparing point clouds as a representative format against other existing modes of landscape architectural representations.
- Work in collaboration with other disciplines to link modified point cloud scenarios directly with analytical models in order to test their performance.
- Uncovering the implications to the discipline of landscape architecture.
- Finally, relate the findings back to the issues plaguing the Ciliwung River.

1.5.2 Uncovering the Representative and Performative Potential of Point Clouds

The thesis first aims to develop a set of tools and workflows specifically designed to enable the manipulation of existing point cloud data so as to be able to inject new proposals back into the model. The same set of tools will then allow these new proposals, represented as 3D point cloud models, to be fed into numerical models for quantitative analysis. The development of the set of tools are not intended for mass market use but are meant to be an experimental exercise to help other software developers understand the requirements landscape architects might have when it comes to working with point cloud models and to include the array of tools in their own software suites. More importantly it enables the hypothesis to depart from one which is purely descriptive - only writing about the possibilities of using point clouds for landscape architecture - to one which is demonstrative - showing that it is indeed possible and uncovering the benefits and issues associated with this.

Once the tools have been developed, the thesis then explores the efficacy of adopting a point cloud workflow in the representation of landscape architecture and the running of analytical models through it. In terms of representation, landscape architects have long recognized the need to not only have sound ideas but also be able to communicate them effectively (Entwhistle and Knighton 2013a). Such representations of landscape architectural ideas can take place in many forms, from paintings to perspectives; maps to motion graphics. The thesis explores if point clouds can be used to completely replace or supplement these traditional (plans, sections, elevations, perspectives) and non-traditional (virtual reality, reality based physical models) representations of landscape projects.

For the performative aspect, the thesis seeks to find a way to feed it directly into numerical models without having to create a separate intermittent format. A fair amount of work in the realm of computer science has been done to extract geometry out of raw point cloud data. This conversion to a surface model is often used to improve the visualisation or to help in injecting semantics into the model and is done through technical algorithms developed by the computer vision, photogrammetry and computer graphics disciplines which attempt to do so automatically (Tang et al. 2010; Awrangjeb et al. 2013; Zhou and Neumann 2013; Hron and Halounová 2015), or through semi-automated and manual means using the base point cloud model as a reference (Apollonio et al. 2012; OUTR 2015). In contrast to this desire to move away from the a point cloud format, the thesis seeks to "stay in the cloud" and to view it as the main 3D model on which the user can interact with and visualise (Nebiker et al. 2010). It argues that remaining in a point cloud format allows for more flexibility in injecting early stage design proposals which can be tested while remaining suitable enough for visualisations. This avoidance of the need to create intermediate 3D model is something which researchers in BPS have identified as a hurdle in integrating simulations into the early stages of design and an emerging preference towards simulations which provide performance feedback directly into native design tools (Negendahl 2015).

Understandably, the technical components of performance testing will unlikely ever be completely handled by the landscape architect alone but would require close collaborations with specialists in other fields. As with all interdisciplinary work, there are variances in methodologies, tools and techniques which are further compounded by conflicting working cultures, operating scales and epistemological differences. These dynamic tensions between disciplines however could become the catalyst which drives creativity and innovation and should be viewed as a strength (Musacchio et al. 2005). The thesis thus seeks to push for the point cloud format as one which bridges these disciplines allowing designed scenarios to be tested and subsequent results being projected back into the original point cloud model to be further studied and visually communicated.

1.5.3 What this means for Landscape Architecture

With the ongoing rapid advancements in computational powers leading to an explosion of digital techniques used in the representing of landscape architecture, the question now is how this move towards a digital realm will alter our understanding and creating of landscapes (Corner 2014). For example, the availability of a high resolution 3D model of the landscape even without the landscape architect lifting his pen or mouse will certainly provoke questions in both pedagogy and practice. Gone is the need to meticulously measure or survey a landscape, study existing maps and satellite images to create the base data from which to begin working from. Field work is cut down and the site can be revisited digitally at the convenience of the designer or planner. In practice, the landscape architect can now become the surveyor himself with the use of consumer grade UAVs, LiDAR scanners and software capable of bringing home vast amounts of precise data. This convenience of serving the terrain on a digital silver platter to the landscape architect or planner runs the risk of a diminished mental understanding of the landscape as he no longer needs to physically and mentally work on building up the underlying digital or analogue base (Sennett 2009a).

Yet this risk is worth taking considering how immense an influence aerial imagery was to the discipline and profession (Waldheim 1999) and how the shift towards a geo-referenced three dimensional framework when working with landscapes is expected to offer improved support spatial organization and decision making (Lange 2001). Perhaps it might even go so far as to help in the understanding of a site through the four step process outlined by Girot (Girot 1999; Deming 2011): Landing (the first encounter with a place), Grounding (the sorting and analysis of collected data), Finding (the discovery of an underlying strategy) and Founding (the generation of a design). While there is no substitute for visiting the site in person (Landing), the ability to revisit a site repeatedly through a 3D point cloud model might alter the other three processes as discoveries and possibilities are uncovered through repeated observations, dissections and modifications of the collected model.

1.5.4 What this means for Jakarta

While the evaluative component of hydraulic flood simulations planned are far from being exhaustive when it comes to a holistic approach to river and flood risk management (Chan et al. 2012), the thesis does so in an attempt to address this most pertinent issue in Jakarta today. The proposed methodology of utilizing reality captured data to spring board the creation of different scenarios which are subsequently tested with numerical quantitative flood models and eventually visualised for the purpose of exacting change will hopefully be able to shed some light on the alternative flood mitigation strategies. This exploratory aim is also targeted to project findings on the work in Jakarta in an easily digestible manner to be consumed by various stakeholders and members of the public who have no prior scientific knowledge of the matter at hand. Understandably, it is clear that the exact solution to flooding will neither be developed by this thesis nor by the group, but we are hopeful that the findings and communicative avenues created along the way will serve as a starting point for more holistic river management polices to be taken into serious consideration.

1.6 Contributions

The thesis lays the ground for further work to be carried out with regards to the application of point cloud data in landscape architecture. Specifically, the thesis has found that a point cloud workflow integrating landscape architectural representations and performance testing is indeed a possibility. In the process, the thesis has highlighted certain key areas which contribute to the discipline of landscape architecture:

- The thesis developed a suite of tools which not only serves as body of knowledge by itself but also enabled the thesis to demonstrate this capability of keeping representation and performance testing within the same point cloud format. However, the thesis finds that for this to advance any further, a much more sophisticated software package will be required which not only leverages off parallel computing but more importantly has a native and expandable set of tools which center around working with point cloud models.
- It was found that between serving as a representative and a performative format, point clouds are more suitable to perform the latter. In this thesis this is largely due to the difficulties in creating realistic representations owing to the limitations in the tools developed. The thesis calls for more representational tools to be developed, such as a detailed point cloud based vegetation library as well as means to easily texture, light and otherwise provide atmospheric conditions are required to improve the representative aspect of the work.
- In contrast, the thesis finds that point clouds can be quite readily fed into quantitative or mathematical models. While there were certainly issues with the testing models used, the inherent structure of a point cloud model - with each individual point having its own metadata - provides an effective means to interface with external testing platforms. What is required is for a means to embed custom metadata into the point cloud such that multiple attributes can be appended to each point to make analysis easier.
- In this light, the thesis finds that point clouds could serve as an effective early design stage testing and decision making format, whereby representations need not be realistic but multiple scenarios can be quickly generated and tested to find the best performing one.
- Unfortunately, while the work has been presented in Jakarta multiple times, it is unlikely that the thesis or the research done by the rest of the group would make a significant impact in the actual remediation strategy currently being undertaken on the Ciliwung River.
- Regardless of the issues discovered, it is clear that reality captured point cloud models will change the way we obtain baseline topographical and spatial data. While traditionally this would have required the combination of multiple sources of information, emerging technology is now available to the landscape architect to obtain a detailed and geo-referenced point cloud model of the landscape which serves as the starting point of inquiry. This shift towards starting with reality capture data will surely be adopted in the near future.

Chapter 2 - Methodology

2.1 Overview

The nature of the discipline and the questions the thesis attempts to answer are inherently diverse, as such the methodological approach to answering these questions requires the adaptation of knowledge from a range of different disciplines such as landscape architecture and planning, hydrodynamic modelling, landscape ecology, Geodesign, photogrammetry and computer science. In order to test the hypothesis that point clouds are a possible representative and performative format for large scale landscape architectural projects, the thesis uses the Ciliwung River as a case study to explore the possibilities of alternative remediation strategies. To do this, the thesis breaks the process down into several sequential but interwoven steps (Fig 2.1). The first being the acquisition and processing of reality captured landscape data in the form of 3D point clouds (Chapter 2.2); the second is the development of appropriate tools and workflows to enable the manipulation of the collected point cloud data (Chapter 2.3); the third is the development of alternative future scenarios (Chapter 2.4); the forth is the integration with external quantitative or numerical models (Chapter 2.5); and the last is the demonstrating of representational potentials developed and experimented with along the course of the project of both the designed scenarios themselves as well as the integration with results from the testing process (Chapter 2.6). During the course of this, analysis on the effectiveness of adopting a point cloud workflow is done using a phenomenological approach (Groat and Wang 2013) in which the experiential process of building and working with the tools and workflows developed provides insights into the questions being asked.

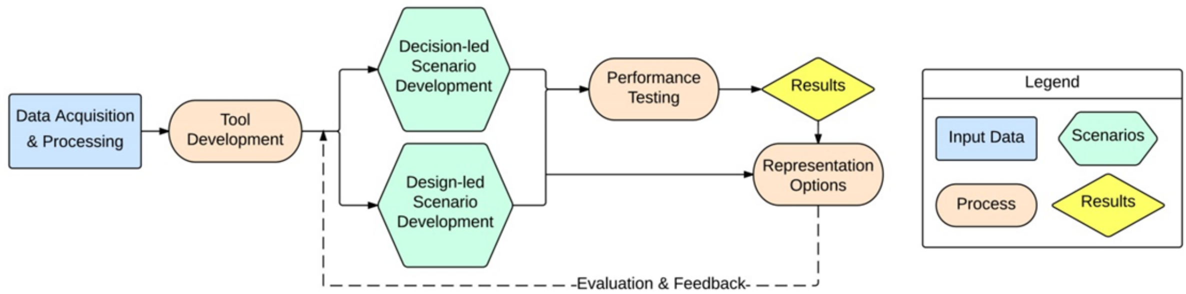
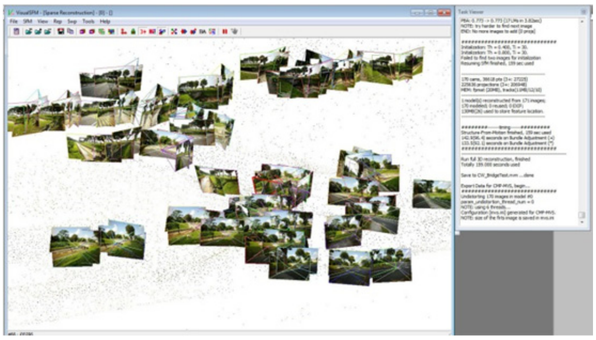


Fig. 2.1: A flow chart indicating the sequential steps being taken by the thesis and how an iterative loop might be formed during this process.

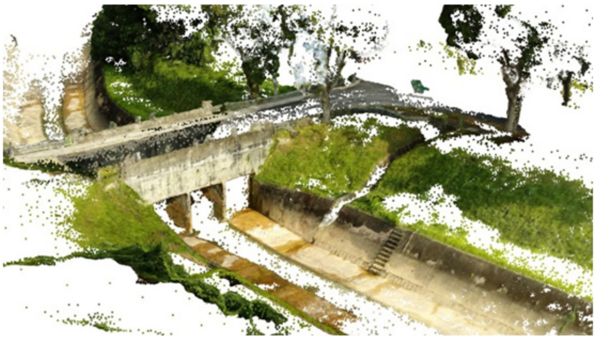
This iterative loop echoes that of Geodesign which loops through models of representation, process, evaluation, change, impact and decision (Steinitz 2012d). Representation (how the study area should be described) in the case of this thesis is pre-determined in the form of a 3D point cloud model. The issues of change (how might the landscape be altered) and decision (how the landscape should be changed) are addressed by two strategies outlined by Steinitz et al. which can be used to develop alternative future scenarios, a design-led and a decision-based strategy (Steinitz 2003). The subsequent stages of process (how does the landscape operate) and impact (what will changes in the landscape result in) are addressed by leveraging on expertise in the multidisciplinary group to adopt hydraulic simulations to address the issue of flooding and the use of landscape metrics to uncover corresponding quantitative changes in the underlying landscape structure. Lastly, the process of evaluation (is the landscape working well) ties in with the need to visualise the results of the simulations and communicate them to the various stakeholders.

2.2 Data Acquisition & Processing

Reality-based surveying techniques refer to the use of hardware and software to metrically survey the reality as it is, documenting a site in 3D through the use of images (e.g. photogrammetry), range-data (e.g. LiDAR) or other techniques founded on capturing data from reality (Manferdini and Remondino 2010). This differs from the creation of 3D data through computer graphics software without the actual surveying of a site, a task which is commonly performed in landscape architecture to recreate the existing 3D site model from an empty digital canvas. The possibility for an end-user to collect and generate reality-based point cloud models (Fig 2.2) which represent vast areas in 3 dimensions makes it particularly promising when dealing with projects such as the Ciliwung River whereby existing data is scarce, inaccurate or simply unavailable. Obtaining such a point cloud model serves as the starting point for the rest of the thesis to take form and brings us away from traditional 2 dimensional representations often used at these scales. It should be noted that data acquisition and processing, although necessary, are not the focus of this thesis and while comments will be made about the benefits and challenges on obtaining the data will be discussed, the actual technicalities lie in the disciplines of photogrammetry, computer vision and other related sciences.



Freely available software is now able to process photographs taken from a consumer grade camera into 3D models (Wu 2011; Jancosek and Pajdla 2011).



The resultant point cloud model representing the bridge and canal that was photographed.

Fig. 2.2: Initial tests done with the consumer grade cameras and freely available software prove that it is now possible for end users to generate reality captured data of landscapes.

Data acquisition at the different scales requires different approaches (Fig 2.3). The smallest scale in which the team responds to relates to the actual on the ground data collection between the streets and alleys of the site, and was the first reality captured data collection method to be employed owing to the relatively low barriers of entry. These close range techniques used by other members of the team include the mounting of of low cost equipment such as consumer grade cameras onto to hand held or pole mounted holders as well as remote controlled quadcopters or more advanced equipment such as terrestrial laser scanners (Rekittke et al. 2012b, 2013b, 2013a, 2014). The density of settlements along the river with their labyrinth of roads and alleys make these ground based campaigns essential to understanding the spatial quality of these settlements from an inhabitant's perspective by allowing the researchers in the team to capture data under the canopy and roofs otherwise obscured from view when seen from the aerial platforms used to survey the landscape.

Data from the local scale can be collected by a variety of techniques. Here a colleague is testing the use of a depth camera to capture this data in situ (Ninsalam 2013).

Data from the site scale is collected using UAV technology. Here, a workshop was conducted in collaboration with the Institute of Technology Bandung showcasing the use of UAVs to capture data of the landscape.

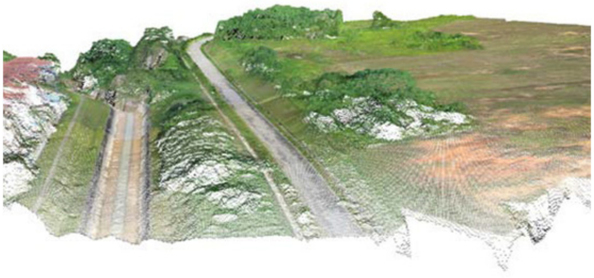
Resultant high resolution reconstructed point cloud models are extremely powerful tools to represent the complex nuances at the local scale.

Georeferenced point cloud model of the ITB campus from images taken with the Sensefly UAV and processed with DroneMapper ('DroneMapper Aerial Imagery Processing and Photogrammetry' 2013).

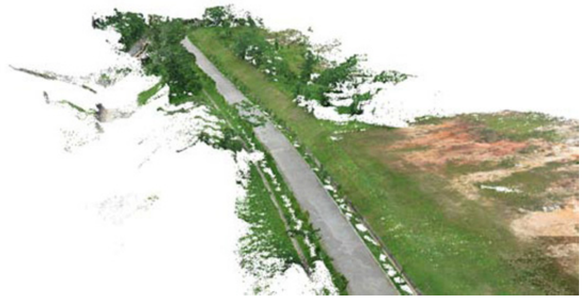
Fig. 2.3: Data from different scales require different techniques and approaches each capable of producing a 3D point cloud model of the site.

The thesis however operates at the site and corridor scales, at the site scale, photogrammetric techniques were explored using UAVs also known as unmanned aerial systems (UAS). In an in-depth review of the current state of UAS technology, Colomina and Molina highlighted the ever increasing trend of using such systems in a variety of applications; agriculture and environmental monitoring; intelligence, surveillance and reconnaissance; aerial monitoring in engineering; cultural heritage; traditional surveying, conventional mapping and photogrammetry, and cadastral applications (Colomina and Molina 2014). The lowering costs and increasing availability has seen UAV technology trickles down to the mainstream population with researchers looking to using them as low cost autonomous tools for mapping, monitoring and managing habitats and natural resources (Koh and Wich 2012; Paneque-Gálvez et al. 2014). The thesis thus similarly utilized UAVs to capture data over the study sites (Chapter 3.2).

The final output of each of the above mentioned data collection methods yields a point cloud model at their own respective scales and can all be geo-referenced and nested into the same virtual environment (Fig 2.4). While there are significant differences in the collection and processing of data, resolution, and expanse of coverage, visual quality and accuracy, there is still a need to administrate, analyse, represent and manipulate these three dimensional models to describe the elements within them and the processes which affect them (Gruen 2008), which is where custom tool development comes in.



Georeferenced point cloud model obtained from UAV data.



Non-georeferenced point cloud model obtained from oblique images from a quadcopter.

Non-georeferenced mesh model obtained from oblique images from a quadcopter.

Aligning and nesting the models together to form a more complete model.

Fig. 2.4: Initial tests show that while the data might be collected and processed differently, it is possible to align and nest the different models in the same 3D environment in order to supplement the base data collected.

2.3 Tool Development

With all its accuracy and visual eye candy of the collected data, there still is a need for the designer or planner to critically source, filter, prioritise and relate the otherwise sterile data in order to engage and control these increasingly complex landscapes in order to find solutions to ever increasing complex design issues (Melsom 2014). In the case of a point cloud workflow, there needs to be a way to effectively generate new designed scenarios to be tested during the early stages of design. This ability to "sketch" in design ideas has been identified as a key area of further development for Geodesign. ESRI's ArcSketch and Google's SketchUp are possible solutions (Goodchild 2010) along with a multitude of other software platforms each with their own advantages and disadvantages (Welihinda and Krishnarajah 2012). However for the purpose of this thesis, other than just the ability to generate scenarios, the software platforms also need to be able to natively deal with point cloud data. In 2007, Fernandez et al. documented the growing number of software platforms which allow for the visualisation, segmentation, transformation and mathematical operation of point cloud data (Fernandez et al. 2007). While these platforms originally catered more towards engineering disciplines, since then others which are commonly used by designers and planners have begun including point cloud capabilities within their existing software suites, this includes products by major software providers such as Esri, Autodesk, Bentley and McNeel. All of these platforms now support the ability to not only visualise but also perform a multitude of operations on a given point cloud dataset. Unfortunately these tools did not include operations which were required by the thesis, such as the exporting the point cloud model into suitable formats for quantitative analysis or the creation of new point clouds for the insertion of proposed scenarios. As such, a set of tools and workflows had to be developed.

To do this, the thesis made use of McNeel's Rhinoceros (a 3D modelling software) coupled with Grasshopper (a visual dataflow modelling plugin to Rhinoceros). Two of the strongest reasons for working with Rhinoceros is the fact that it firstly already had an inbuilt - albeit limited - support for point clouds and secondly it allows for the positioning of point cloud data in its world co-ordinate system which has no restrictions for geometry to be centred around the origin ('Rhinoceros - Accuracy' 2013). This means that point cloud models in Rhinoceros can be positioned in its 3D space which can be related closely to Universal Transverse Mercator (UTM) co-ordinates, making future collaborations with other members of the group who are working in other GIS platforms easier. Together with Rhinoceros, Grasshopper's visual dataflow modelling approach requires only basic if not no scripting skills and instead operates through the use of a symbolic language of "box-and-wire" connections (Fig 2.5), thus making readily accessible to designers and very effective for design explorations (Janssen and Chen 2011; Celani and Vaz 2012). Users who desire even more functionality can further extend the use of Grasshopper by creating their own custom components (Sitler 2010) through the use of textual programming languages which are better suited to handle large-scale and complex problems (Leitão et al. 2012). This ability to create and share custom tools created for Grasshopper has created an online network of available commercial and non-commercial add-ons to the plugin which further extend the usability of the platform. As a result of this flexibility and customizability, the combined use of Rhinoceros and Grasshopper has been adopted in both the discipline and profession of landscape architecture (Fricker et al. 2012b, 2012a; Amoroso 2014a; Biggs 2015).

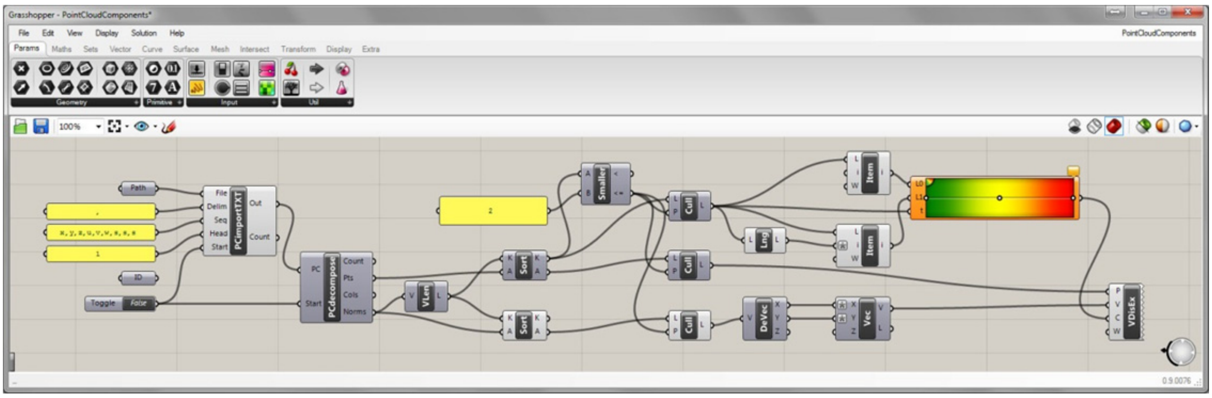


Fig. 2.5: A typical "box-and-wire" setup in Grasshopper in which a series of nodes, each representing a particular function, are strung up sequentially to create a final algorithm which requires no scripting knowledge and thus makes it easily accessible to designers.

The resultant custom built "Point Cloud Components" consist of three main tool categories (Chapter 3.3); modification tools allow for direct operations on imported point clouds; representation tools which allow for the creation of new point clouds; and simulation support tools which export the point clouds for use with external simulation software packages (Lin and Girot 2014). In unison they have allowed for the possibility to embed proposals into the existing base point cloud data as well as being subsequently exported for use in quantitative analysis.

While the designing of the tools described are expected to demonstrate the technical possibility of working with point clouds, there is a simultaneous objective to explore the efficacy of adopting such a workflow. Knowledge and understanding of the underlying design problem and its solution are acquired in the building and application of the artefacts which address the issue at hand (Recker 2013). Such artefacts can be manifested as models, prototypes, theories or in this case the tools developed. Tools are used to perform a given task, to enable enquiry or to enhance an otherwise hindered capability and they originate as an innovative product of inquisition to a particular task at hand. If designed successfully, they will provide evidence of an implicit understanding of the problem by the designer of the tool (Loveridge 2012). As such, other than the obvious technical and demonstrative utility which the developed tools will provide, it is expected that there will be other insights brought to the surface as a result of the actual designing and application of the tools.

2.4 Scenario Development

This desire to test a building or landscape design extends to assist in the decision making process between different alternative future scenarios (Steinitz et al. 2003) whereby a limited number of possibilities are created and systematically compared against one another (Deming 2011). An alternative landscape futures approach (Steiner 2000) or more simply put, the development and evaluation of alternative scenarios, is a common technique used in the decision making process. In the US, the National environmental Protection Act includes legislation requiring the development and analysis of alternatives prior to the approval and commencement of projects (US EPA 2015). A similar approach has been adopted by the EU in which the onus lies on the developer to evaluate potential alternatives and deduce the least invasive solution through a systematic approach (Europeran Commission 2015). This development of a scenario thus extends beyond the superficial to encompass the assumptions, objectives and requirements that guide the underlying design of a study and forms an important process in the decision making process (Steinitz 2012e).

Owing to the complexities involved in the planning of a landscape, it is unlikely if not impossible that a single scenario emerges. As such the development of multiple alternative scenarios serves as a means for decision makers and stakeholders to investigate each proposal against a range of identified targets. To achieve this, there has been an increasing call for numerical models to quantify such targets which allow an analytical approach to predicting the responses of a landscape that is subjected to a variety of alternative changes (Bolte et al. 2007). These targets serve as an effective and widely used tool in approaching environmental planning (Bryan et al. 2011) and can include the direct and indirect effects on a range of factors including: human beings, flora, fauna, soil, water, air, climate, landscape, material assets and cultural heritage, as well as the interaction between these various indices. Bryan et al. went on to develop a "landscape futures analysis" method which attempts to quantify the environmental, economic and social impacts of possible future scenarios. Instead of attempting to encompass this full range of performance indicators, the thesis focuses on the development of scenarios which are targeted to uncover potential solutions to the salient issue of flood management and mitigation for the Ciliwung River. It does so through the development and injection of different scenarios into the base 3D model thereby adding an additional spatial element – topography - to the simplified 2D models typically used for such analyses. In doing so it seeks to identify potential preliminary scenarios which exist within the realms of plausibility with the hope that they would be taken on by the administration and developed into more well informed designs and plans in Jakarta.

In the development of scenarios, the thesis looked towards both a design-led strategy - in which design ideas are used as the driver for change - as well as a decision-based strategy – in which top down decisions inform of the interventions to be made. Approaching the issue using a design-led strategy, a series of possible alternative future scenarios were created through design explorations by a series of Design Research Studios (DRS) (Fig 2.6). These DRSs consisted of undergraduate students led by lecturers in both the Landscape Visualization and Modeling Lab (LVML), under the Chair of Landscape Architecture at the Swiss Federal Institute of Technology Zurich (ETH Zurich), as well as the Masters in Landscape Architecture (MLA) course at the National University of Singapore (NUS). A total of 4 DRSs took place over the course of 2 years and all of them operated in the same Kampung Melayu and Bukit Duri sub-districts in Jakarta – the downstream site. Of the 4, the thesis will attempt to draw inferences from the differences in results of the first and last studios as the author was actively involved in these two DRSs.

The first group of DRS students in the field in Jakarta from the MLA course in NUS (2012).

The final DRS started with an international workshop comprised of students from Jakarata, Singapore and Switzerland (2013).

Fig. 2.6: A series of Design Research Studios (DRS) were carried out to explore different design-led scenarios of the downstream Kampung Melayu/Bukit Duri site.

The first studio carried out in 2012 consisted of 11 students from the NUS and was carried out before any UAV campaigns took place; as such they relied purely on data collected directly from their field work and publically available maps of the area. The last DRS began with an international workshop which was facilitated by the Future Cities Laboratory (FCL) in 2013 and involved 47 students and seven faculty members from four different institutions. Unlike the first DRS which had no additional data to rely on, students at the workshop had access to high resolution maps and ortho-rectified aerial photographs generated from the UAV campaign of their respective study areas. Groups of students were tasked to develop their ideas which were aimed to discern the present landscape and urban situation of the river, and to develop a set of alternative proposals that take into account flood risk, together with opportunities for urban and landscape change. In particular, after the workshop, students from ETH Zurich were provided with the point cloud tools developed in order to assist in evaluating their designed scenarios by running flood simulations through them (Girot and Melsom 2014). Details of the results from these two DRSs are described in chapter 4.2 and inferences will be drawn from the differences between results produced by the two DRSs.

The design-led scenarios stretched the limits of plausibility and were limited to dealing only with the downstream site and production would have been hindered by the need to learn how to use the developed point cloud tools. In contrast a separate decision-based strategy was employed that tested scenarios which more realistically reflected the possible immediate future of the river, applied over a longer stretch and developed by the author - who would not be obstructed by having to learn a new set of tools. A total of six scenarios divided over two sets were tested, the first set was based solely on changes in land use while the second set was based on large scale topographical changes along the river corridor. In the first set, 3 land use change scenarios were created to test if changes in the amount and fragmentation of vegetation along the riparian corridor would make any difference in the simulation results. The second set of scenarios consists of a series of topographical changes along the river corridor based on potential decisions made by the administration; this includes a full normalisation (canalisation) scenario, a partial normalisation and a green infrastructural scenario. All six scenarios described in detail in chapter 4.3 were similarly evaluated using flood simulations.

2.5 Performance Testing

River rehabilitation is one area of science that can benefit from the increased interaction between a 3D digital model of landscape design and the numerical modelling of river hydraulics (hydrodynamic modelling). Integrating these two very different models provides for the potential to not only produce topographically and geographically accurate visualisations but also with the help of simulations can lead to a better understanding of the impacts particular scenarios have. Methodologies for the use of point clouds for hydraulic simulations are starting to be explored and LiDAR data is already used as base topographic data for urban flood modelling (Kehl and Haan 2013; Abdullah et al. 2013; Meesuk et al. 2015). These point cloud based hydraulic simulations however, stop short of analysing and proposing alternative scenarios. In contrast, the thesis presents an approach to the integrated modelling of river rehabilitation scenarios through direct modifications of the underlying point cloud data. This helps produce multiple 3D scenarios which when integrated with hydrodynamic simulations allow us to make better informed decisions by understanding not only the existing conditions of the Ciliwung River, but more importantly simulating and predicting the flood mitigation potentials of possible future scenarios to aid in the decision making process.

To predict how well the different proposed scenarios perform with respect to flood mitigation, the thesis relies on the interdisciplinary mechanics of the module to incorporate hydraulic simulations into point cloud workflow (Lin et al. 2016). The point cloud models of each scenario were exported using the tools developed into a format suitable to be used directly in 2dMb (Faeh 2007; Shaad 2015) - a two-dimensional hydrodynamic model developed with the intent to study flood propagation in complex and steep terrain (Chapter 3.4.2). Understandably, river processes typically extend over tens of kilometres and as such the resultant datasets become similarly large. While point clouds can provide unprecedented details at multiple scales, developing intervention schemes at those scales and modifying them to compare current and future scenarios is both a design and a computational challenge. Using high resolution hydrodynamic modelling to evaluate some of these intervention strategies requires significant computational effort, made possible not only by the increased adaptation of parallel computing but also through the use of more detailed and physically based numerical models to capture the complex interaction of the terrain with the river flow. A parallel version of 2dMb (Shaad 2015), using the Open Multi-Processing (OpenMP) directives has been developed that was used to carry out the simulations in this thesis. By using a two dimensional hydrodynamic model solving the full shallow water equation, the study attempts to push the simulations to their computational limits.

In addition to the topographic data, which is crucial to the integration with hydrodynamic simulations, semantic information (e.g. classification information) if embedded in the individual points will enable for more effective processing, analysis and visualisation (Richter and Döllner 2014). While it has been shown that LiDAR point cloud data can be used to identify urban land use, detect vegetation and otherwise segment the data into distinct classifications or objects (Höfle et al. 2012; Zhou and Neumann 2013; El-Ashmawy and Shaker 2014; Yan et al. 2015), neither aerial LiDAR data nor the expertise to dissect it were available. In addition, while the UAV campaign revealed high resolution topographical data, the available land cover data was too coarse to be used (Fig 2.7). As such land use classification was done through simple spectral analysis of the satellite image coupled with manual identification of patches of vegetation with the eventual classification and friction information embedded into the metadata of each individual point in the point cloud (Chapter 3.4.1). These friction values provide an additional layer of information during the flood simulation as water does not flow in the same manner over different land covers. Classification information is used not only to visually inspect the arrangement of riparian vegetation but is also explored as a means to make quantitative measurements on landscape patterns.

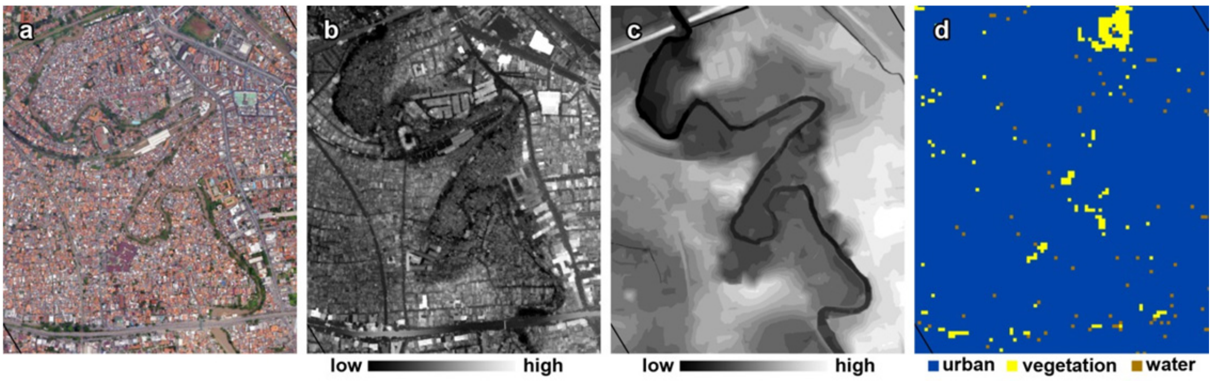


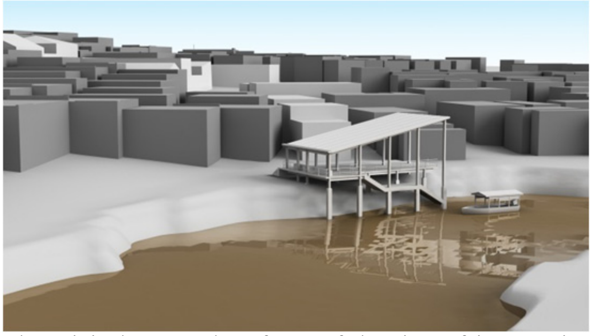
Fig. 2.7: The resultant data obtained from the UAV survey include (a) an orthophoto, (b) DSM and (c) DTM. It is immediately obvious by visual comparison that there is a wealth of information not captured in the publically available (d) land cover data for 2010 ('Land Cover Data Year 2010 in WS 6 Ci (ALOS)' 2010).

Identifying and categorising these patterns are an essential input required in the calculation of landscape metrics which serve as a quantifiable form of analysis (Mas et al. 2010). To do this, the thesis utilises FRAGSTATS (McGarigal et al. 2012), a spatial pattern analysis program traditionally used for 2D categorical maps, not 3D point clouds. FRAGSTATS allows for several forms of input data, the easiest format being an ASCII grid which we export from the modified point cloud data. FRAGSTATS is very well documented, freely available and calculates more than 100 landscape metrics, as such it is the most complete program at present to run such analyses (Zaragozí et al. 2012). This development of quantitative landscape ecology has been accelerated along with improved computer processing capabilities and has found a place in the assessing and planning of landscapes, quantification of landscape functions as well as ecosystem services. A review of the current trends in the use of landscape metrics also uncovered a lack of studies which attempt to uncover regulation functions and values of natural and semi-natural ecosystems and landscapes, such as flood and erosion control (Uuemaa et al. 2013b). Together with the flood simulations being carried out, the thesis thus attempts to uncover if there is a correlation between the results of the simulations and a selected number of landscape metrics to understand if the two methods can serve as a performative analysis of proposed scenarios.

2.6 Representation Options

Lastly, as the thesis also investigates the use of point clouds as a representative format for landscape architecture, several representation options will be explored throughout the course of the thesis both to represent the scenarios generated as well as the results from the simulations. Landscape representations occur in a multitude of different mediums for different purposes and while Treib gathered literature describing the nuances of the various traditional forms of landscape representations (Treib 2008a), Amoroso compiles a very diverse visual catalogue of examples from a range of academic institutions (Amoroso 2012a). In her latest book, Representing Landscapes: Digital (Amoroso 2014b), Amoroso specifically draws examples of representations which were produced digitally and catalogues them into 6 main “drawing types”; Diagrams and Mapping Drawings; Presentation Plans; Section-Elevations; Axonometric Drawings; Perspectives; and Digital Modeling and Fabrication. In many ways these categories echo those identified by Treib and can be seen as the digital evolution of long standing traditions in landscape representations. The thesis thus looks to these categories to see how the developed point cloud workflows fit within these established categories in order to supplement or even supersede them.

Of these six drawing types, the perspective is perhaps the most controversial. Constructing a three dimensional impression of a landscape through a two dimensional medium, this technique developed since the Renaissance has been used by landscape architects since the time of Repton and has evolved into the digital renderings generated by computers so often seen today. Even with the digital precision provided by computers, the critique of perspectives is often that they are subjective from the moment a stationary point of view is chosen, and more often than not from the most persuasive location (Andersson 2008). The digital medium goes further to very easily allow a combination of various sources of visual information (3D models, photographs, hand drawn sketches, etc) into a digital “photoshopped" collage-montage (Fig. 2.8) that has now become a standard medium and visual representation type in the field of landscape architecture (Cantrell and Michaels 2010b; Amoroso 2012b).



The original 3D render of one of the sites of intervention from the first DRS.

The final perspective comprised of a collage of hand drawn plants and details into the original 3D render.

Fig. 2.8: Perspectives created from a combination of several digital and analogue sources such as this has become a standard medium for representations in landscape architecture.

The proliferation of these readily understandable digital perspectives, fuelled by advancements in technology, have diluted the significance of a plan, but a carefully crafted presentation plan is still able to capture the qualities of a design to give the viewer a more accurate understanding of the design (Zeunert 2014). The drawing of a plan is to create a guide to which some form of action takes place, it is a directive document that illustrates the relationships between different elements in a landscape and thus embodies the design (Treib 2008b). Presentation plans thus have their strength in enabling constructions and is still seen as a cornerstone of landscape representation. In contrast to presentation plans which are synonymous with construction, the practice of mapping is still seen as an integral part of the creative process and has long been associated with the planning and design of cities and landscapes. This abstraction of reality by the creator of the map serves to convert information into visuals with the goal of improving clarity with an appropriately chosen visualisation method (Hansen 2014). As such while mapping can be seen as a process of understanding the landscape, the creation of plans forms the step forward by proposing an intervention.

The other two orthographic projections - elevations and sections - provide a topographical reading of the site, revealing vertical spatial relationships which are otherwise not apparent in plans (Ortega and Anderson 2014). Sectional representations of a site also have the potential to reveal geological as well as atmospheric dimensions and require a different spatial understanding to read them as opposed to maps and plans (Pousin 2013). In particular, the section across the river is crucial to the thesis considering how flood channel design by hydraulic engineers occurs through development and assessment of a series of sections down the river (Fig. 2.9). Here the section is the most revealing, clearly illustrating the width and depth of the river, its bank angle and any reinforcements, materiality, underlying geology and the relationships with the neighboring urban fabric.

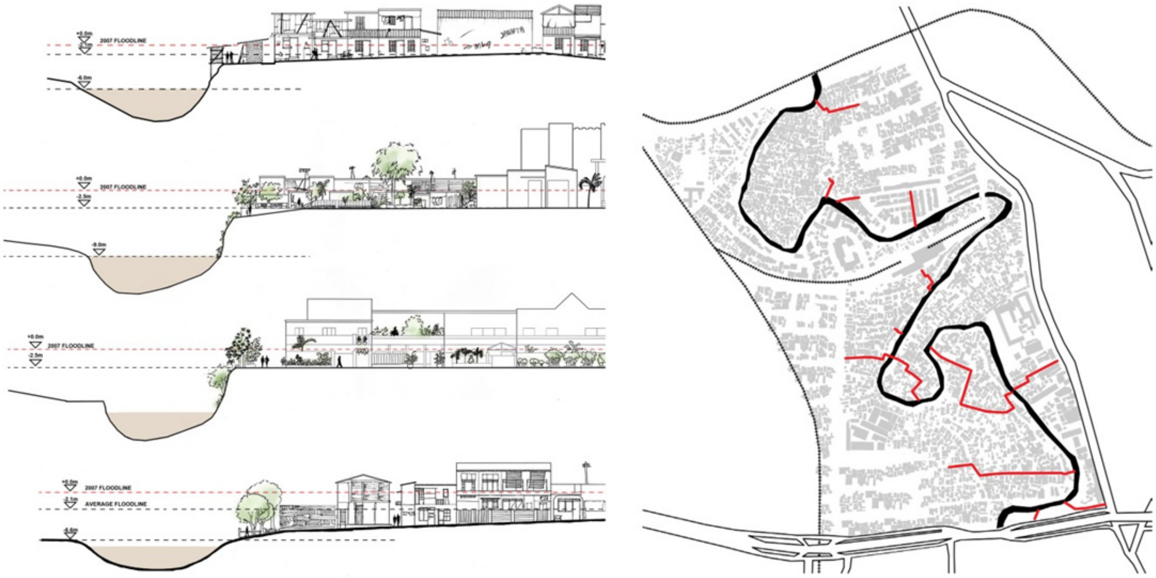
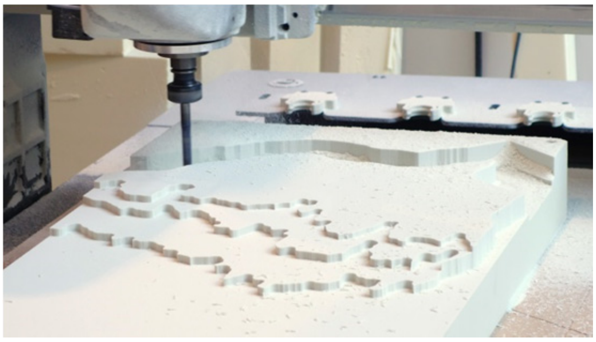


Fig. 2.9: Sections and maps were one of the primary representation formats used by the students in the first DRS. Here the sections indicated the estimated bathymetry, surrounding context as well as the estimated flood levels.

Axonometric drawings use a 45 degree rotated plan with elements projected vertically to create a pseudo three-dimensional image that has no distortions due to foreshortening but as a result can feel a little unnatural (Entwhistle and Knighton 2013b). This lack of foreshortening however provides for a unique ability for the various elements in the drawing to hold a similar visual weight as objects in the foreground do not get enlarged compared to those in the background and as such represents the landscape as it is known to the mind not to the eye (Imbert 2008). The axonometric drawing is particularly useful in illustrating how different parts fit together to form a whole, such as in mechanical engineering, this potential can extend into landscape architecture by explaining the intricacies within each layer of the design while simultaneously demonstrating how these layers spatially fit together to form a whole (Counts 2014a).

The final “drawing type”, digital modelling and fabrication, is one which has shortest historical background but is perhaps where point clouds would be best categorized under. Its closest analogue is the creation of physical models which have historically exist throughout the various stages of landscape architectural design as an experimental and exploratory settings (Dreiseitl 2005) as well as in flood hazard modeling where numerical modeling alone is insufficient to simulate the complex dynamics required (Bellos 2012). These physical models can manifest themselves through the use of realistic representations of landscape elements or the even the quick and malleable medium of molding clay (Walker 2008; Rieder 2008) but the advent of digital fabrication has since automated the process (Fig 2.10). Regardless of the means of production, the process of creating and viewing such physicalized models in landscape architecture allows for not only the representation and understanding of proposed designs but are also instrumental for the manipulation, analysis and expression of ideas, forms and relationships available in this three-dimensional space (Nijhuis and Stellingwerff 2011).



A digital model is fed into a Computer Numerical Control (CNC) milling machine which mills a block of foam down to the indicated form of the digital model.

Using digital fabrication, models of different scales can be milled. Here a section across the river is milled along with the proposed interventions.

Fig. 2.10: Subtractive digital fabrication consists of the removal of material from an original block until the predefined form is created, shown here with the use of a 3-axis Computer Numerical Control (CNC) milling machine.

As long as these representative formats have been around, there have been arguments for and against each of them. While such digital models allow for real time perspectives to be viewed from an infinite number of angles thus allowing the viewer to quickly understand the overall configuration of the landscape itself (Counts 2014b), the generation of a final perspectives from one still threads the thin line between a legitimate representation and one which is purely picture making. Corner has likewise been cautious about the ability for representations of landscape architecture to transcend beyond the superficial, arguing that presentation plans, sections and elevations have a less convincing role to play as an imaginative and exploratory medium (Corner 1992b) than the creative process of mapping, which according to him, is an inherently subjective, interpretative and fictional construct of reality (Corner 1999b). Yet it is specifically this subjectivity and the need for interpretation which have eroded the credibility of constructed landscape architectural representations. The discussion here is whether the unbiased nature of a reality captured point cloud model can alleviate this subjectivity and challenge the long standing tradition of interpreting the various layers of information of a landscape into a representative visual medium. The thesis does this by exploring various representative options such as the ones described above to draw comparisons between them. Here, the visual quality, ease of creating such representations as well as the efficacy of using them to communicate ideas will be highlighted.

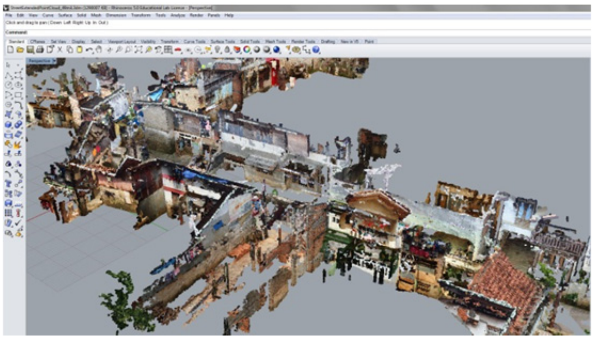
Chapter 3 – Data, Tools & Testing

3.1 Overview

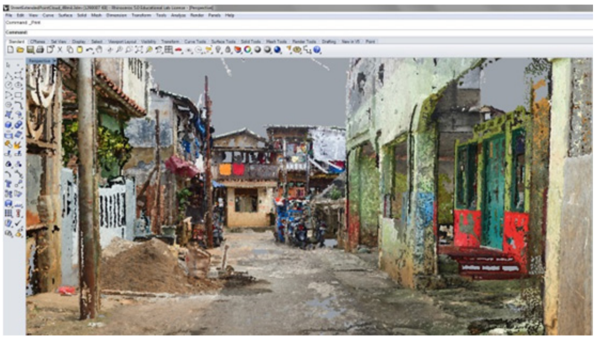
Chapter 3 deals with the technical aspects of the methodological flow chart laid out in the previous chapter. This begins with the details of the data acquisition and processing techniques used for obtaining the required base point cloud data of the identified sites (Chapter 3.2). As mentioned before, obtaining the data is just the initial step, details of the tools developed to work with this data as well as examples of how they are used are described next (Chapter 3.3). Lastly, the setting up of the two performance testing methods used - hydrodynamic simulations which help to simulate flooding and landscape metrics which provide a means to quantify the underlying landscape structure - are described in detail (Chapter 3.4).

3.2 Data Acquisition & Processing

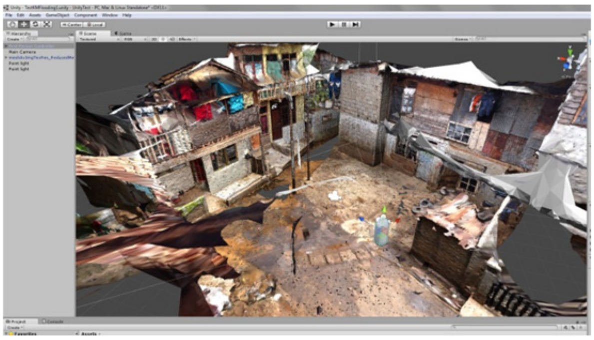
While awaiting the permissions and equipment necessary to carry out the main UAV campaign, several other low-cost techniques were employed in order to kick start the point cloud data collection process and to experiment with the tools and methods to work with such data (Rekittke et al. 2013b). The method with the lowest barrier of entry was through the use of consumer grade digital cameras to capture photographs which were then be processed into 3D models. Here, close range terrestrial techniques convert still photographs into 3D models using freely available software packages such as VisualSFM (Wu 2011) and CMPMVS (Jancosek and Pajdla 2011). The resultant models (when successfully reconstructed) provide a highly detailed and visually realistic representation of the captured landscape and can not only be worked with through 3D modelling software packages such as Rhinoceros but also developed into an interactive walk through environment (further explored in Chapter 5.2.3) which allows the user to explore the model from a first person perspective similar to a video game interface (Fig 3.1).



The most successful model captured using this technique required almost 1400 photographs to capture a street within the Kampung Melayu district.



The final model consisting of 42 million points offers an realistic representation of the urban landscape next to the river.



A down-sampled mesh of the captured model can be used to set the "stage" for the character to explore

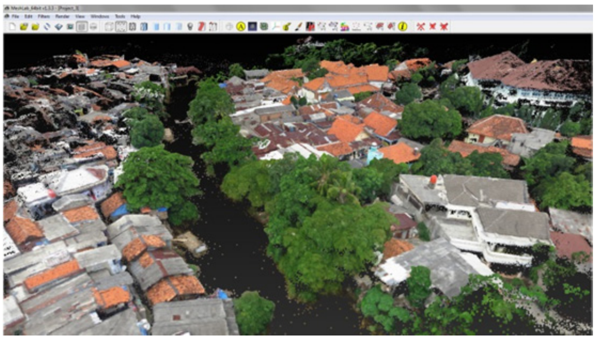
The interactive walkthrough interface allows the user to explore the model in a first person perspective much like a in a video game environment.

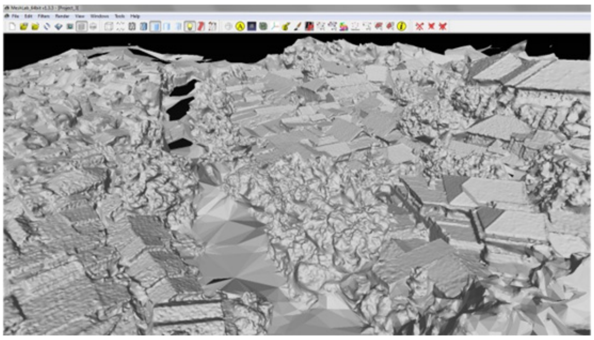
Fig. 3.1: A series of 1400 photographs were taken along a street which runs perpendicular to the Ciliwung River in the downstream Kampung Melayu site. These photographs were then processed into a 3D point cloud model and viewed either in Rhinoceros or made into an interactive environment in which the user can explore the model in a first person perspective.

While these models were visually realistic, the fact that the photographs captured only the facades of the buildings meant that the reconstructed scenes were absent of any depth to the buildings. In addition, when attempting to apply the same method to the river banks, the terrestrial method of walking along the street proved nearly impossible along the banks of the river as they were riddled with obstacles. The sheer density and complexity of the urban fabric coupled with the need for much larger areas to be captured for flood simulations to be run, meant that this method of data collection would take months if not years to complete. The solution was to utilise aerial remote sensing techniques instead to capture a much larger area, albeit with less resolution and detail.

The terrain data collected at the site scale was done so through the use of UAVs. While the final UAV campaigns took only a morning or two per site, the lead up to being able to do this proved to be a very arduous process with red tape, safety concerns and conditions on the ground hindering the process. Prior to this, two other small scale UAVs were tested in the field, a home-made quadcopter as well as an off the shelf Swinglet CAM UAV (senseFly 2015). It was envisioned that data from these platforms could be used to supplement data collected from terrestrial sources such as laser scans (Fricker et al. 2012b). The quadcopter experiment was designed to capture short segments of the river from a height of 50m. Oblique photographs from an attached camera were used to generate a 3D model using the same software packages described earlier (Fig. 3.2). Unfortunately, due to reasons unknown, the quadcopter on its second attempt lost radio control and crashed. Thankfully no damages or injuries resulted but any further experiments were called off citing safety concerns.


An example of a photograph taken from the quadcopter which provides an aerial perspective unobtainable from any terrestrial vantage point.


Using the same structure from motion software packages, a 3D point cloud model can be obtained from the photographs taken by the quadcopter.


The un-textured mesh model is able to recreate some of the water surfaces, unlike the point cloud model.

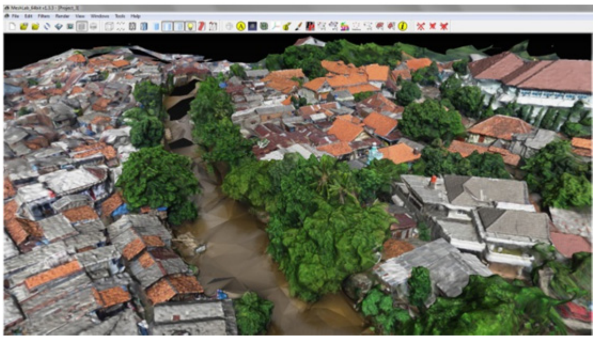

The textured mesh model reconstructs trees and roof surfaces with a fair amount of realism.

Fig. 3.2: Oblique images from a quadcopter were used in an attempt to generate 3D models of the river and its immediate surroundings.

The Swinglet CAM UAV was the second system that was tested in the field with guidance from the Institute of Technology Bandung (ITB). This very portable system and was designed to allow end users to create their own maps on the spot and on demand with a decent 0.02-0.2m level of accuracy (Küng et al. 2011). A sharing workshop was carried out with local students from the ITB and sample data was generated over their new campus grounds (Fig 3.3) as well as a portion of the upstream Ciawi site.

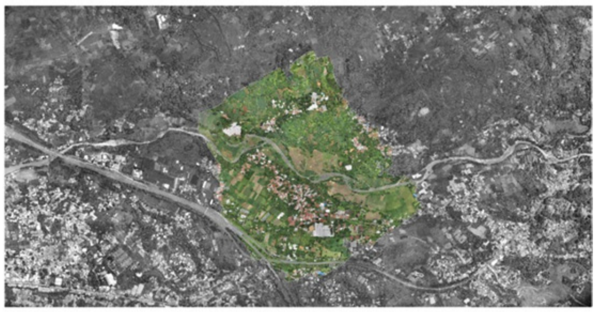
A UAV sharing workshop was carried out with students from the ITB to showcase the capabilities of the Swinglet CAM UAV (2013)

The Swinglet CAM UAV was flown over ITB's new campus and the results processed into a point cloud model.

Fig. 3.3: UAV Sharing workshop with ITB students and results from the Swinglet CAM UAV.

Unfortunately it was quickly apparent that this platform would prove unsuitable for use in Jakarta. While the light weight flying wing (<500g) with its crash resistant foam construction can be seen as harmless should it accidentally hit into something, this also means that it is very susceptible to environmental conditions, in particular wind, and as a result campaigns had to be carried out only in the best of weather conditions. More critically, the lack of suitable landing strips is a known issue faced by operators using fixed wing UAVs - such as the Swinglet CAM - which require a large clear area in order to land safely (Paneque-Gálvez et al. 2014). For the ground resolution desired, the Swinglet CAM could only capture an area of approximately 1.5km^2 at a time, as such it would require several campaigns launched from multiple launch locations over each of the three sites. The lack of suitable landing strips at all the identified sites made it impossible to utilise the system to its full potential (Fig 3.4).

An approximately 1.5km^2 portion of the upstream Ciawi site was mapped using the Swinglet CAM UAV. This was done in less than ideal conditions as a suitable flat landing area could not be identified.



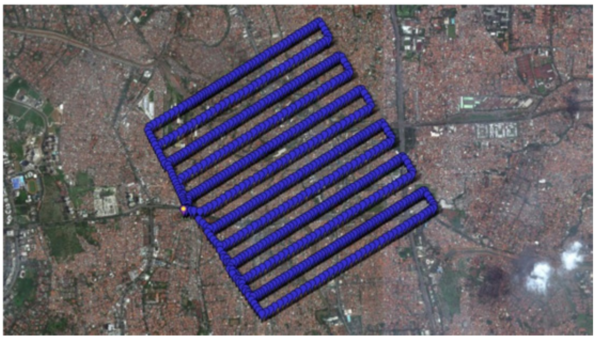
A comparison between the coverage of a single Swinglet CAM mission against the entire area of interest required indicate that there needs to be around 5 missions and as a result 5 more suitable landing areas.

Fig. 3.4: Results from a mission carried out with the Swinglet CAM UAV which shows the limited range of the system when compared against the entire area of interest. The resultant difficulty of finding suitable multiple landing spots across the entire landscape made it inefficient to use this UAV for the rest of the data acquisition campaign.

The eventual final UAV campaign was carried out by working in collaboration with colleagues from the Simulation Platform at the Future Cities Laboratory ('Simulation Platform | Future Cities Laboratory' 2013) and the ITB which not only commissioned the use of a custom built gasoline powered model helicopter but more importantly assisted with obtaining the required permits for the campaign. This process alone, took over two years to come to fruition as multiple delays, failed tests and other complications stood in the way. Thankfully the eventual campaigns were executed without any hiccups and all three sites were covered in a timely fashion.

The resultant images consisted of between 400 and 700 images per site, taken from a height of approximately 400m along a predetermined flight route (Fig 3.5).

The gasoline powered UAV which was commissioned to carry out the campaign had the range and flight duration capable of covering an entire site in a single morning.



Instead of having to find multiple large landing sites, a single landing pad was all that was required to cover the entire 5km^2 downstream site with 650 photographs.

Fig. 3.5: The commissioned UAV was custom built to carry the required payload to a height of 400m and had the range and flight duration to cover an entire 5-9km2 site in a morning or two.

These images were initially processed with an online service ('DroneMapper Aerial Imagery Processing and Photogrammetry' 2013) to create a preliminary geo-referenced point cloud model representing the Digital Surface Model (DSM) to work with. This DSM represents the tree canopies, roof tops and water surfaces and creates a realistic mand accurately geo-referenced reality captured representation of the landscape (Fig 3.6).

Fig. 3.6: Processed georeferenced coloured 3D point cloud data of all three sites were obtained from this final UAV campaign covering between 5-9km2 per site.

However, as the sensors (in this case a compact digital camera) onboard the UAVs are not able to penetrate through obstacles, further processing and data collection needs to be done to find the actual ground under these occlusions, the Digital Terrain Model (DTM). This generation of the DTM was initially done automatically using LAStools ('LAStools' 2013), a software capable of efficiently processing billions of LiDAR points. In this case the point clouds were converted into a format which LAStools was able to run one of its algorithms designed to automatically extract ground points. While imprecise, this was the best available data at the time and was then used by the final DRS onto which to build their scenarios (Chapter 4.2.2). To obtain an even more accurate DTM, the data was further processed in-house by members of the Simulation Platform; this required a human operator to meticulously compare pairs of photographs from the UAV campaign in order to pick out suitable ground points which were then interpolated to form the resultant DTM. This task proved to be extremely challenging for downstream Kampung Melayu/Bukit Duri site as the density of settlements meant that few observable ground points were visible from the air.

It should be noted that all of these methods are still unable to uncover the underlying bathymetry of the river, as such a further campaign was organized in order to manually measure the bathymetry of the river (Ninsalam et al. 2015) and this data was subsequently embedded into the DTM using the tools and methods developed. The final combination of all these techniques results in a DTM in the form of a gridded point cloud with a 1m horizontal resolution at 0.1m vertical accuracy, devoid of any obstacles such as buildings, bridges or vegetation but embedded with a river bathymetry and exported in a format suitable for the flood simulations (Fig 3.7).

Fig. 3.7: The original DSM (left) while useful for visualisation purposes was not suitable for flood simulations due to the presence of obstacles, for that a bare earth DTM was required. An intermediate DTM was generated using LAStools (middle) which automatically tries to flatten out the buildings and trees but ultimately human intervention was required to clean up the DTM as well as to embed the river bathymetry manually into the model (right).

Lastly, unlike the site scale which relied on UAV data, the corridor scale terrain model was based on the merging of two different datasets:

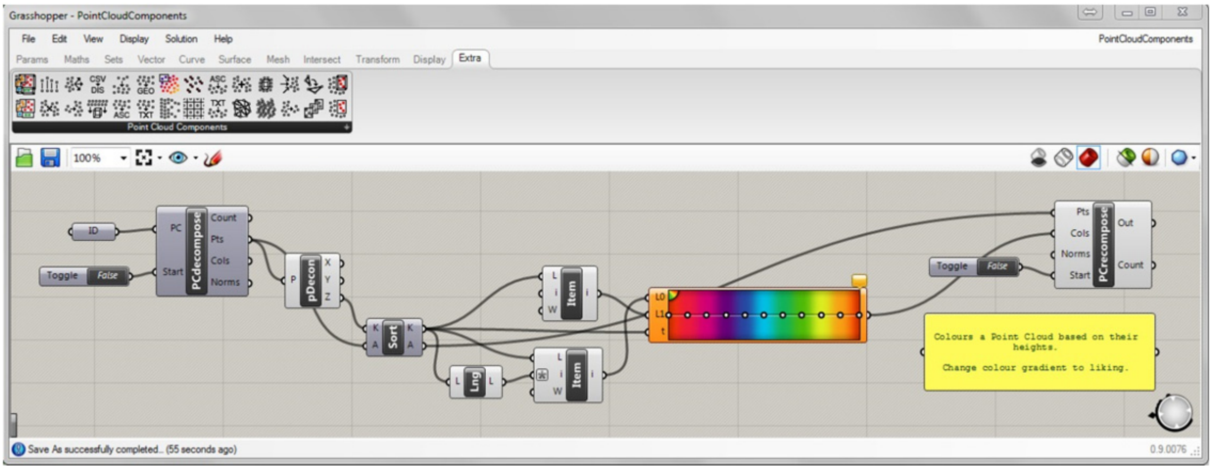
1. IfSAR DTM: Interferometric Synthetic Aperture Radar (IfSAR) is a well-established remote sensing technology that uses electromagnetic energy of a specific wavelength to gather elevation and location data. The data collected was obtained from Tarumanagara University (Untar) which collected IfSAR data between January and March 2000 using an aerial survey. The DTM extracted from it is at 5m resolution and hydraulically corrected (structures such as bridges have been removed and water bodies identified). This DTM was acquired to represent the floodplain and landscape area for the river corridor but lacked the bathymetry required for the flood simulations.

2. Surveyed River Cross-sections: The river bathymetry data is derived from a one-dimensional river model of the Ciliwung developed using the Hydrologic Engineering Centers River Analysis System (HEC-RAS) and was obtained from the Ministry of Environment (Indonesia). The model covers nearly 40km of River length containing 750 cross-sections surveyed cross-sections – thus, one cross-section every 50-100m along the river. By interpolating these cross-sections along the spline of the river, a 3D digital surface model of the river bathymetry as a triangulated irregular network (TIN) was constructed.

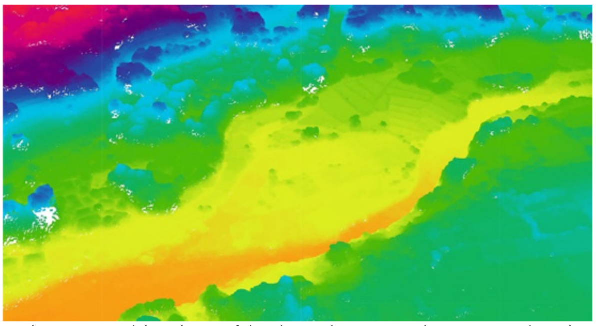
The TIN of the river bathymetry was then manually geo-referenced and merged with the IfSAR DTM to create the surface bathymetry used for the original and land use change scenarios (Shaad 2015). The final surface model with a resolution of 5m was subsequently exported as an American Standard Code for Information Interchange (ASCII) grid to be imported as point cloud model for further modifications with the tools developed as described in the following chapter 3.4. This manual geo-referencing of the cross-sections is expected to introduce some irregularities into the model which would surely defer from the reality on the ground, and thus it would be more accurate to limit to comparative analysis amongst the scenarios developed as opposed to referencing them directly to reality.

3.3 Tool Development

The development and refinement of the tools created was carried out throughout the duration of the thesis and new tools were created when their specific need arose. These “Point Cloud Components” (Lin and Girot 2014) have been developed to provide the ability to work with point cloud datasets in order to not only embed proposed future scenarios but also to enable qualitative analysis to be performed on them. Written in C# and accessed through Grasshopper, a plug-in to Rhinoceros, the final set of 28 different tools adds a lot more functionality to the 4 very limited tools native to Rhinoceros. As mentioned, Grasshopper’s visual dataflow modelling system requires only basic if not no scripting skills thus making it readily accessible to designers to further extend the capabilities of the tools developed using either their own tools or nodes already available in Grasshopper (Fig. 3.8).



The original point cloud model and its original RGB colours based on the UAV images makes for a realistic representation but elevation data is hard to decipher.



Using a combination of both native Grasshopper and Point Cloud Component tools, it is possible to replace the original colour information with a colour ramp indicating the elevation changes.

Fig. 3.8: The visual dataflow modelling environment allows existing Grasshopper nodes to be linked up with the developed Point Cloud Component tools. In this example, PCdecompose is used to access only the coordinate data of the points in a point cloud, after which Grasshopper tools are used to sort the data by height and a colour gradient is then appended to the height information. PCrecompose combines the original point coordinate data and gradient into a new point cloud model with a colour gradient based on height.

One of the biggest limitations identified from the onset of the tool development process is the sheer number of points that needs to be dealt with. The number of points in these models often goes into the tens of millions, if not more, and results in computational bottlenecks; an issue which plagues all software platforms attempting to deal with massive point cloud models. The problem increases exponentially as many of the tools require cross references to each and every point in the cloud - a doubling of the number of points can result in more than a quadrupling of the amount of time required to run a specific tool. To alleviate this issue, the tools developed have been simply parallelised where possible to make use of all the processor cores available on a given computer effectively reducing the amount of time taken to a fraction of the non-parallelised versions (Table 3.1).

Table 3.1: One of the tools developed, PCgrid, was used to simplify a point cloud with 16 million points from a resolution of 0.5m to 50m. The resultant time was recorded to measure the improvements derived.

Description	Time Taken (Minutes)
Non-parallelised version of PCgrid	84 mins
Parallelised version of PCgrid on a computer with 6 cores	12 mins
Parallelised version of PCgrid on a computer with 18 cores	6 mins

The developed tools are broadly classified into three different categories: modification tools, representation tools and simulation support tools. Modification tools allow for direct manipulation of the point cloud models, such as the ability to extract a certain area or to merge multiple models (Chapter 3.3.1). Representation tools allow for the creation of new point cloud models to represent a proposed intervention (Chapter 3.3.2). Lastly, simulation support tools allow for the point cloud models to be coupled to external simulation or quantitative analysis platforms (Chapter 3.3.3). The following sections detail the tools in each category and provide examples of their usage while further details are elborated in the appendix (Chapter 6.1). It should be noted that the examples shown it here are purely demonstrative of the tools and workflows and are not indicative of actual proposed interventions.

3.3.1 Modification Tools

The modification tools are at the core of the tool development, without which there would be very limited options of manipulating the point clouds other than to scale and move them around in 3D space. These set of tools allow for a variety of modifications which enable the user to dissect the point cloud as well as to recompose and recombine separate point clouds together (Table 3.2).

Table 3.2: Overview of the Modification Tools created to allow for direct manipulation of point cloud models.

Icon / Name	Description	Icon / Name	Description
 PCcrossRef	Combines two point clouds together based on user defined parameters.	 PCreduce	Reduces the number of points in a point cloud object. Useful for reducing computational overheads.
 PCdecompose	Decomposes a point cloud object into its constituent parts.	 PCreference	Transforms a point cloud to fit 3 referenced points
	Extracts points in a point cloud based on user selected colour. Useful for extracting vegetation for example.		Extracts sectional samples from a point cloud. Useful for extracting sections of rivers and roads.

PCextractColour		PCsection	
PCfindDuplicate	Finds duplicate points between two point clouds based on a user defined distance.	PCtrimBrep	Trims a point cloud using a closed brep. Useful for separating identified objects in a point cloud model, e.g. a tree.
PCmerge	Merges point clouds together	PCtrimCurve	Trims a point cloud using a closed curve. Useful for separating identified areas in a point cloud model, e.g. an area of vegetation.

In the following example we make use of the data collected from the upstream Gadok/Katulampa area of the Ciliwung River and propose hypothetical land use changes in order to demonstrate the use of some of the modification tools. In this example an existing plot of land is replaced with a different land-use which is copied from another portion of the point cloud and manipulated to fit in almost seamlessly - a three dimensional cut and paste operation using point clouds (Fig. 3.9).

The original point cloud model obtained from processed UAV images showing agricultural use next to the river.

Using PCtrimCurve, an area of interested is drawn as a closed curve which can be used to remove the points which fall within its boundary.

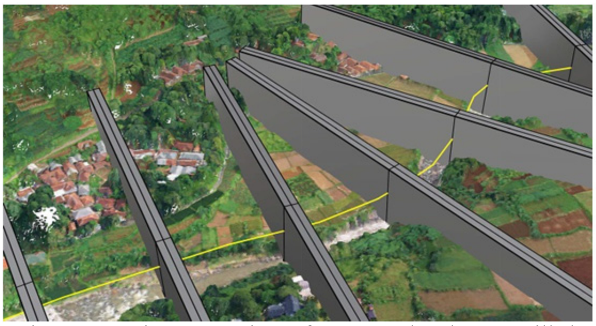
Again using PCtrimCurve, we can alter the appearance of the area by copying from another region of the point cloud and positioning them in place with PCreferenece to quickly represent land use changes.

Essentially a “copy and paste” operation carried out again to quickly represent an urban land use scenario instead.

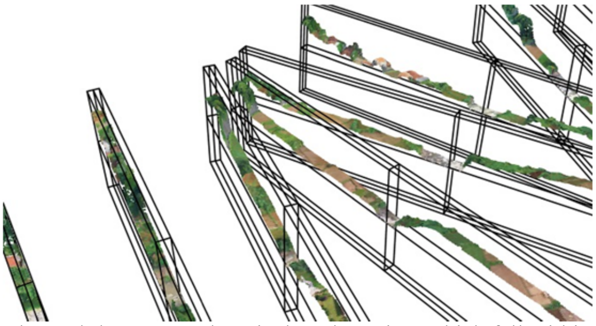
Fig. 3.9: Using the modification tools (in this case PCtrimCrv and PCreference), it becomes possible to copy another region of the point cloud over to visually simulate land use changes

This basic ability to isolate and separate points within a base point cloud model is further extended with the PCsection tool. Developed to create a series of sectional cuts through the landscape, it comes in particular useful for the case study at hand. Using PCsection, we can easily sample slices of the landscape along the course of the river thereby having a clearer understanding of the changes along the riparian corridor (Fig 3.10). While it is difficult to make out subtle topographical changes in the 3D model, these extracted sections make it a lot easier to see how the river width and bank profile changes even across this short 500m sample. A further application of a series of PCextractColour operations will allow the extraction of points of a particular spectrum, in this case green which is likely to represent vegetative cover.

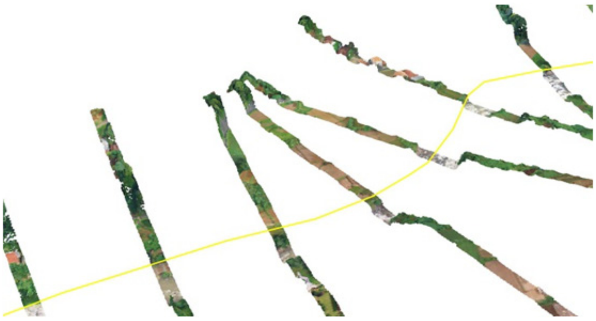
A curve is drawn along the approximate center line of the river.



Using PCsection, a series of rectangular breps will be temporarily created along this center line.



The tool then proceeds to isolate the points which fall within these rectangular breps and extracts them from the base point cloud.



The extracted sections can be viewed in place to make it easier to compare changes in the bank conditions as opposed to viewing the entire point cloud model.

Alternatively, these point cloud sections can then be placed next to each other as a form of visual analysis on how the riparian landscape changes over this particular section of the river.

If required, PCextractColour can be used to extract points of a particular colour range, in this case green which is likely to represent the vegetative cover in the extracted sections.

Fig. 3.10: An example of using PCsection to extract a series of point cloud sections from the base 3D model followed by a series of PCextractColour operations to extract all points which lie in the green spectrum.

3.3.2 Representation Tools

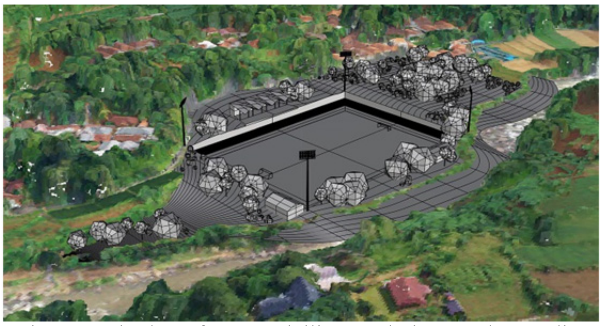
Being able to modify the point cloud data is useful but more important to the thesis is the ability to create new scenarios and to embed them into the base point cloud model as seamlessly as possible. In order for these embedded scenarios to remain in a point cloud format, tools were needed to enable the user to create new point clouds which represent proposed interventions, be it changes in topography, additional vegetation or other infrastructural interventions. This is where the suite of representational tools (Table 3.3) comes in to create point cloud models from scratch which represent the desired interventions as opposed to the "cut and paste" method shown previously in the modification toolset.

Table 3.3: Overview of the Representation Tools created to allow for the creation of new point cloud models to represent a proposed intervention.

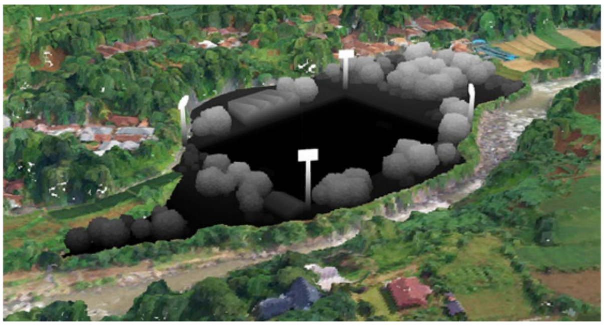
Icon / Name	Description	Icon / Name	Description
PCdensify	Densify a point cloud through simple extrapolation. Additional points are added in between the existing points in the point cloud model.	PCmesh	Converts a point cloud to a mesh using Delaunay triangulation. Works best for gridded point clouds and is useful when generating a mesh to be milled with a CNC machine.
PCdrape	Drapes points over breps to create a point cloud	PCmodel	Creates a point cloud from faces of breps. Useful for generating new point clouds out of surface geometry, such as a new river bathymetry or buildings.
PCembed	Embeds a gridded point cloud into another, replacing original underlying data	PCnoise	Adds random noise to the coordinates of a point cloud object. Useful to break up the otherwise rigid appearance of created point cloud models using PCdrape or PCnoise.
PCfalloff	Creates a gradiented reduction in points from source curve. Was created to reduce abruptness of the jarring boundaries where the collected point cloud models end.	PCrecompose	Recomposes elements back into a point cloud by specifying a list of points, colours and normal. Used in conjunction with PCdecompose to replace the values of the original point cloud, e.g. replacing RGB data with a shaded elevational gradient.
PCgrid	Simplifies a point cloud into a series of square grids. Considering how a lot of the data collected was in the form of regular grids, this tool makes it possible to create new point clouds which follow the same grid as the underlying base data.		

To illustrate this process, a slightly more complex hypothetical intervention was created and represented as a point cloud model. In this case a proposed floodable soccer pitch (Fig 3.11) is created and positioned at the same location as in the example before.

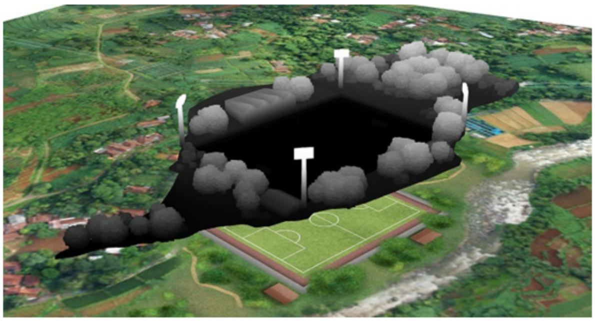
The same region was selected as per the example with the modification tools.



Using standard surface modelling techniques, the stadium ground, trees and buildings were modelled in Rhinoceros. Notice here how distinctly different the surface model looks from the underlying point cloud model.



PCmodel converts all the surface models into point clouds. After which they were merged with PCmerge, decomposed with PCdecompose, sorted for each point's elevational data using Grasshoppers internal tools and lastly a gradient was added resulting in a shaded point cloud created using PCrecompose.



In order to colour the point cloud, the 2D orthographic photograph was used and the elements were coloured in plan (seen here under the point cloud model). The colours were then transferred into the point cloud using a combination of the tools developed with inbuilt Grasshopper tools.

The colouring of the point cloud is a tedious process as each individual element might need to be coloured or shaded to make it look realistic.

The final point cloud model is one which only consists of point clouds and can be viewed as realistic in terms of its visual quality in comparison with the surrounding base point cloud model.

Fig. 3.11: An example of using the Representation Tools in order to visualise a new hypothetical intervention into the existing landscape, in this case a floodable soccer stadium.

The methods shown above can essentially be used to create any proposed scenarios. Unlike the hypothetical stadium shown, a more realistic scenario such as the canalization of the river can also be produced using the same tools and methods (Fig 3.12).

Fig. 3.12: The same technique can be applied for the representation of more realistic scenarios, in this case the possible canalisation of the river.

3.3.2 Simulation Support Tools

The modification and representation tools have shown that it is now possible to alter and inject designs into a base point cloud model. Land use changes can be visualised, river bathymetry can be altered, vegetation can be introduced or removed, what is lacking at this point is the ability to run quantitative models through these new scenarios, that is where the simulation support tools come in (Table 3.4).

Table 3.4: Overview of the Representation Tools created to allow for the point cloud models to be coupled to external simulation or quantitative analysis platforms.

Icon / Name	Description	Icon / Name	Description
 PCclassifyCrv	Separates a point cloud into different layers based on curves created in corresponding layers. Useful for separating the point cloud model by identified area, e.g. vegetated areas or urban areas.	 PCexportGEO	Exports point cloud as GeoTXT grid for 2dMb. Specifically written to integrate with 2dMb flood simulations carried out with the help of the engineers in the team.
 PCclassifyBrep	Separates a point cloud into different layers based on breps created in corresponding layers. Useful for separating the point cloud model by identified objects, e.g. buildings or trees.	 PCexportTXT	Exports point cloud as txt file.
 PCcompare	Simplifies 2 point clouds into grids & measures the differences in height at grid points.	 PCimportASC	Imports point cloud from ASC file. Useful for importing files exported by ArcGIS for example.

PCdischarge

Calculates discharge at a particular location from 2dMb results. Useful for isolating a particular point along the course of the river for analysis.

PCimportTXT

Imports point cloud from txt file. The simplistic but convenient TXT file is useful for transferring data amongst colleagues each using a different software package.

PCexportASC

Exports point cloud as an ASC grid. Useful to export the point cloud into a format that can be used in ArcGIS or FRAGSTATS.

As the thesis deals with the dynamics of a river, the need to be able to simulate the effects of proposed alterations to the river corridor becomes crucial to the decision making process of deciding which flood mitigation strategy best balances the needs of the various stakeholders. To do this, the simulation support tools allow the user to import base data (Fig. 3.13) as well as export the modified point cloud models (Fig. 3.14) into a variety of file formats suitable for use by external simulation platforms. While cumbersome and not the most elegant of solutions, the interfacing file formats between the point clouds in Rhinoceros and the quantitative software platforms are in the form of a human readable text file which is exported with the required information simplified into a grid with the coordinates of each grid cell, its absolute height as well as either a classification or friction value depending on the analysis required.

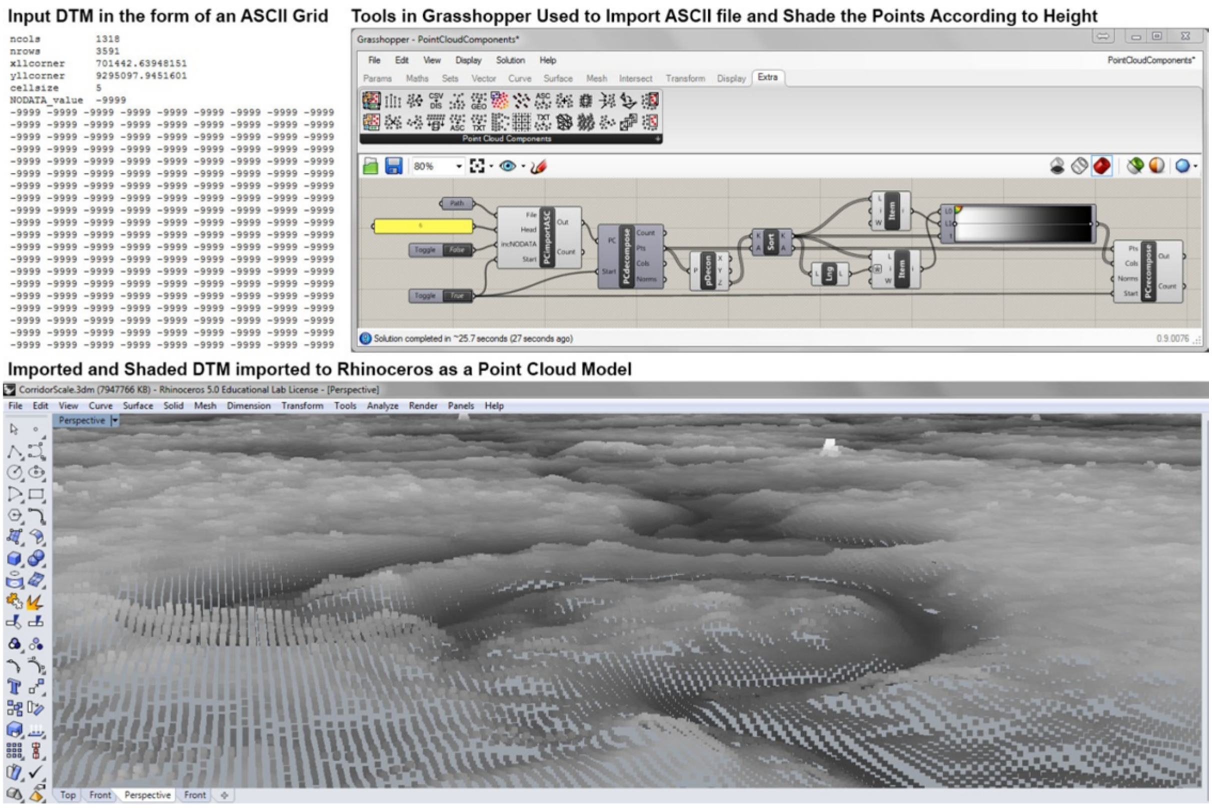
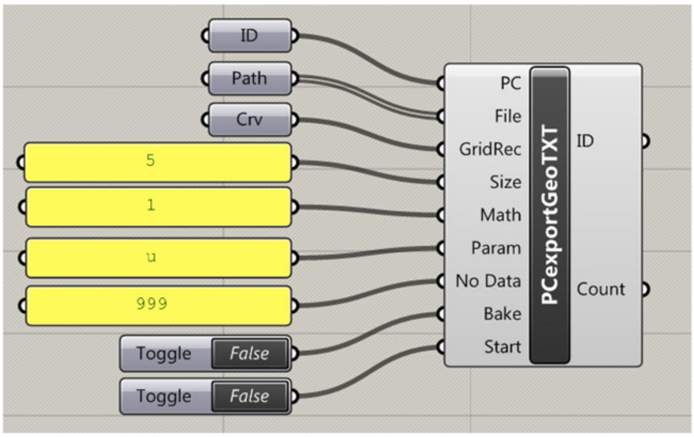


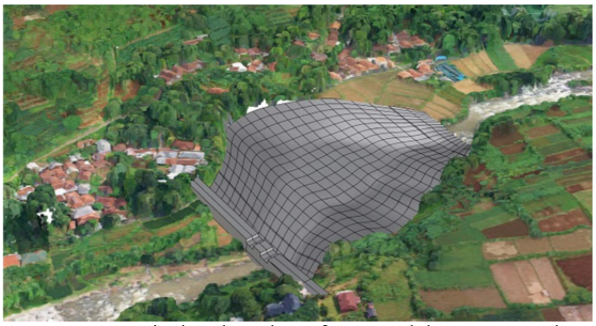
Fig. 3.13: The DTM which was prepared as an ASCII grid format was then imported into Rhinoceros and shaded using the tools built for Grasshopper.



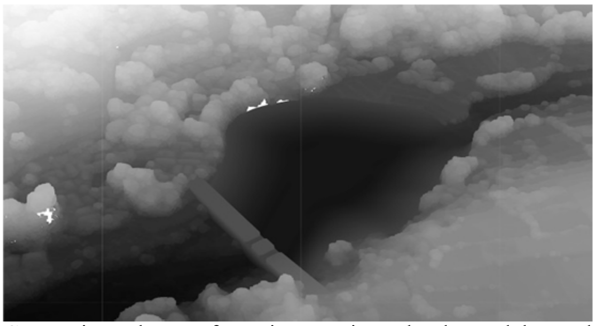

```
>>grid
dx 5 1318
dy 5 3590
zbed 0.001
bed_level_nonstag
1,1,74.6226, 0.01,701445.13948151 9295100.4451601 /
2,1,75.3444, 0.01,701450.13948151 9295100.4451601 /
3,1,76.789, 0.01,701455.13948151 9295100.4451601 /
4,1,77.4608, 0.01,701460.13948151 9295100.4451601 /
5,1,77.5684, 0.01,701465.13948151 9295100.4451601 /
6,1,77.3073, 0.01,701470.13948151 9295100.4451601 /
7,1,78.178, 0.01,701475.13948151 9295100.4451601 /
8,1,78.8424, 0.01,701480.13948151 9295100.4451601 /
9,1,74.40685, 0.01,701485.13948151 9295100.4451601 /
10,1,75.19897, 0.01,701490.13948151 9295100.4451601 /
11,1,76.1949, 0.01,701495.13948151 9295100.4451601 /
12,1,76.88721, 0.01,701500.13948151 9295100.4451601 /
13,1,77.33301, 0.01,701505.13948151 9295100.4451601 /
14,1,77.5182, 0.01,701510.13948151 9295100.4451601 /
15,1,77.4374, 0.01,701515.13948151 9295100.4451601 /
16,1,78.2735, 0.01,701520.13948151 9295100.4451601 /
17,1,76.85431, 0.01,701525.13948151 9295100.4451601 /
18,1,76.30698, 0.01,701530.13948151 9295100.4451601 /
19,1,76.4074, 0.01,701535.13948151 9295100.4451601 /
20,1,75.7599, 0.01,701540.13948151 9295100.4451601 /
```

Fig. 3.14: The PCexportGeoTXT tool grids a given point cloud model and exports it into a format file suitable for use in the hydraulic simulations whereby each line represents a grid cell with the appropriate row, column, height, friction and XY coordinates value

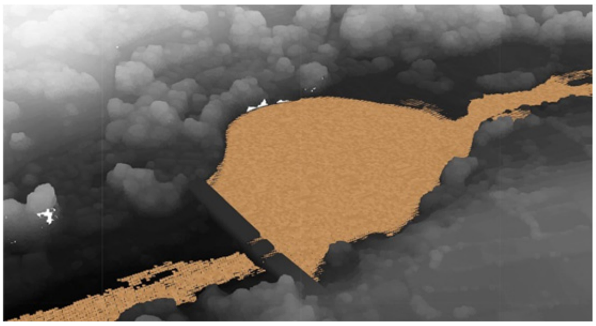
To demonstrate the use of the simulation support tools, we use the same modification and representation tools from before but extend it to incorporate the hydraulic simulation of a hypothetical dam. In this case, the dam operates via a simple overflow as there are no active controls built into the simulation (Fig. 3.15). Details of the setting up of the hydraulic simulation are presented in the following section.



An area was isolated and surface models were used to indicate the new dam as well as the excavation works around it.



Converting the surface into point cloud models and embedding them back into the base model.



Running the 2dMb simulation, the results can be returned back into Rhinoceros using the PCimportTXT tool.

If required the results can be coloured to create a realistic representation of the dam and the subsequent water level at a simulated discharge.

Fig. 3.15: Using a combination of modification, representation and simulation support tools developed, flood simulations can be run off these modified point cloud models and their results can be positioned back into the models for further visual analysis.

3.4 Performance Testing

With the help of the tools developed, the collected data can be imported, modified within Rhinoceros and subsequently, after the scenarios have been developed, exported again to interface with the two performance testing platforms being used. This flow of data, file formats and the creation of scenarios at the corridor scale are summarised in Figure 3.16, of which the first step is to obtain a classified point cloud required to embed the necessary semantic data necessary for the subsequent performance testing platforms.

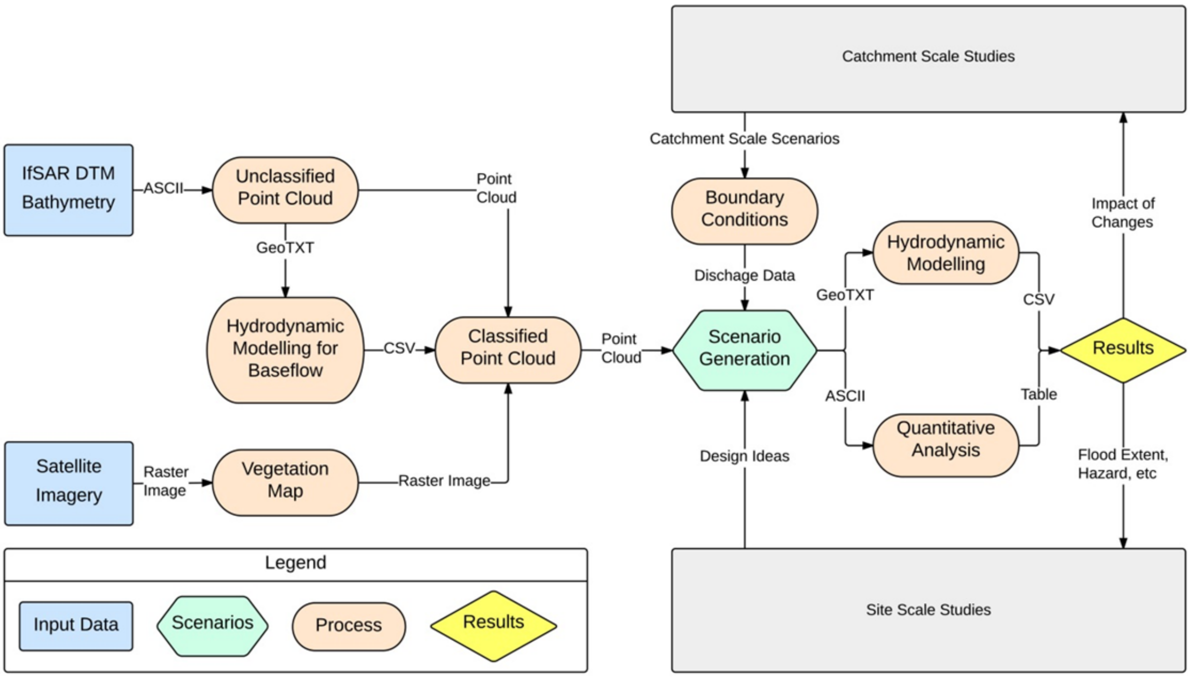


Fig. 3.16:A flow diagram depicting the integrated modelling approach which indicates the flow of data and processes over the corridor scale and the areas in which it interacts with the other two scales.

3.4.1 Point Cloud Classification

Point cloud data collected both at the site and corridor scales are devoid of any classification information and while traditional visual interpretations of high resolution aerial images obtained through remote sensing techniques can provide comprehensive information about an urban site, the heterogeneity of such environments makes it difficult to identify specific urban land uses (Herold et al. 2002). While multispectral satellite imagery can be used to assist in the classification of land cover, this data was not readily available for use. As such the thesis had to make the best use of available data on hand in order to classify the point cloud data. At the corridor scale, land use classification was based on optical examination of satellite image (‘World Imagery’ 2014). As vegetation height, density, species and other related information were not available, a vegetation map was created which classified the identified patches very broadly into two categories; dense vegetation – which consisted of identified areas of tree canopies; and sparse vegetation – which consisted of fields and open spaces. As for the river, since it is typically difficult to accurately identify its extents from satellite imagery, the results of a low discharge ($10m^3/s$) generated from the hydrodynamic model is used instead to classify the river.

Ideally, the information from this vegetation and river classifications would then be embedded into the metadata of the points in the point cloud. However, each discrete point of a point cloud in Rhinoceros currently allows a maximum of 10 values – which are limited to the XYZ Cartesian coordinates, the ARGB colour channels and the UVW normal channels. As Rhinoceros currently doesn't allow for custom metadata to be embedded, the R and U channels were used to embed the classification and friction values respectively. Figure 3.17 shows the process of producing the final classified point cloud model.

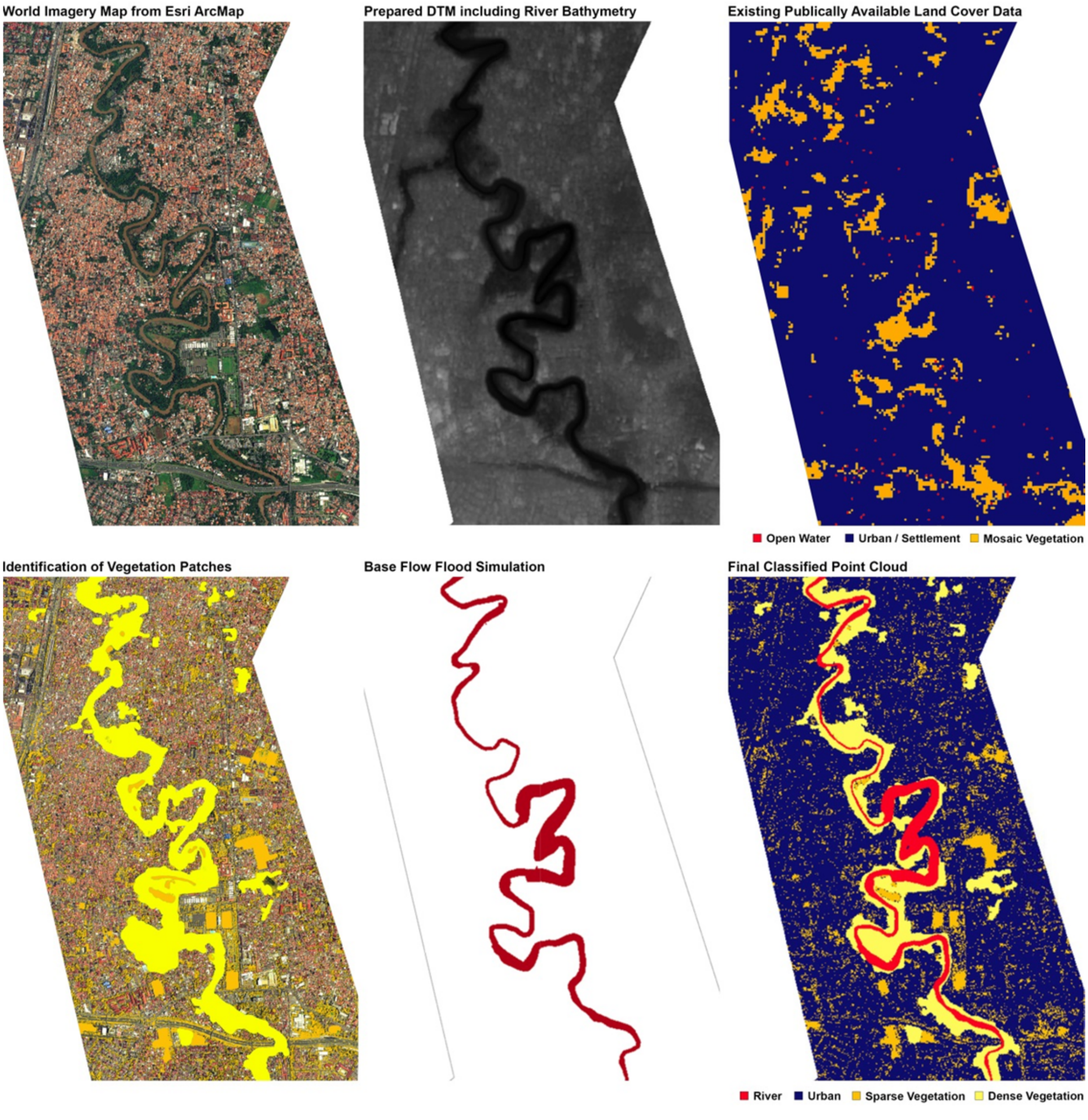


Fig. 3.17: Existing publically available land cover data was extremely coarse at this scale - with the river itself not showing up in the dataset. As such, colour filtering and further manual identification was used to broadly classify the vegetative patches followed by a base flow flood simulation to establish the route of the river within the DTM. These were then stamped into the DTM in Grasshopper to produce the final classified point cloud model.

While the corridor scale consisted of only 4 land cover types (LCTs), there was more information available at the site scale which allowed for a further refinement of the identified LCTs. The output of UAV campaign consists of three components, a high resolution ortho-rectified photograph (orthophoto), the DSM and the DTM. This allows an additional segregation of the LCTs by relying on the third (Z or height) dimension. By measuring the height of objects from the difference between the DSM and DTM (Fig. 3.18) followed by a cross-referencing of this information with colour information provided by the orthophoto, it is possible to stratify both the urban and vegetation layer through a series of filters applied to the point cloud model (Fig. 3.19). This allows us to segregate the points into 10 different land cover types (LCTs) and sorts between open spaces, urban structures of different heights as well as approximating the differences between fields, shrubs and trees in a manner which was impossible at the corridor scale. While understandably not the most accurate of approaches, it provides the thesis a means to proceed to the next stage of its exploration, the interfacing with performance testing platforms.

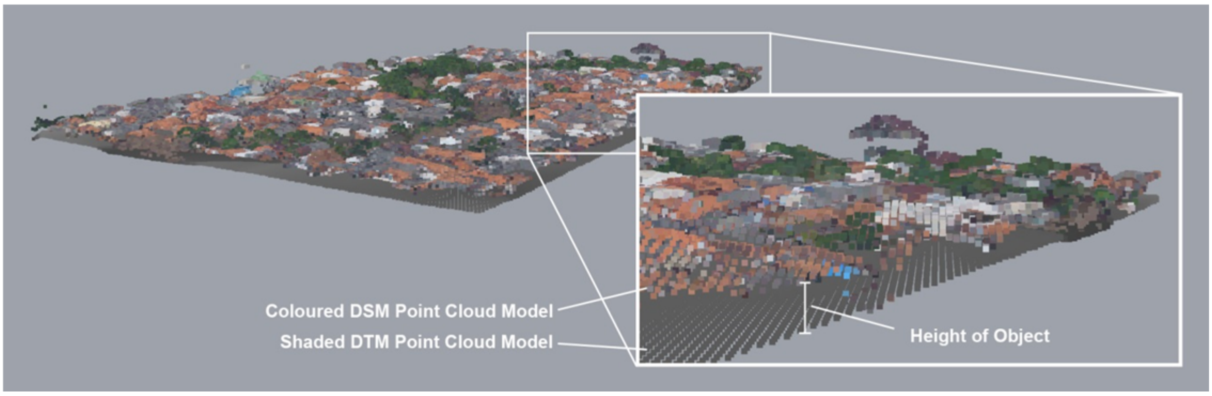


Fig. 3.18: Calculating the difference between the DSM – which represents the top of an object – and the DTM – which represents the bare ground under an object – we are able to obtain the height of an object at that particular point.

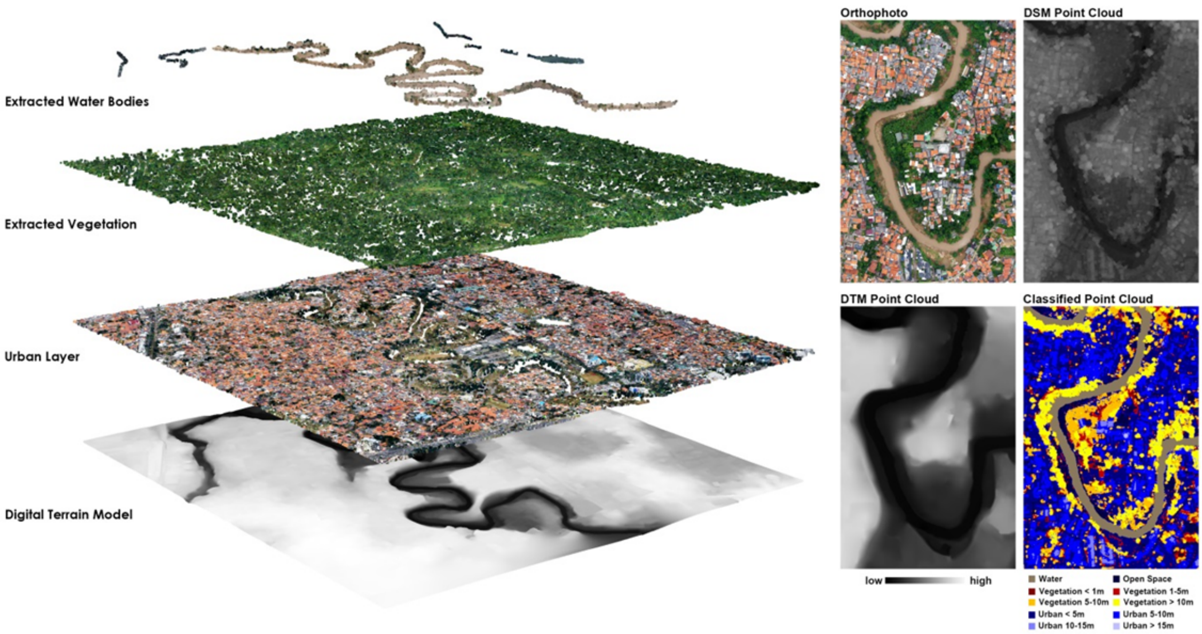


Fig. 3.19: Cross referencing the height information with information from the orthophoto and base DSM point cloud model we are able to segregate the point cloud model into layers representing urban, vegetated and water bodies which are then further stratified based on height. The water bodies were extracted manually using an outline while the vegetation was extracted using a mask prepared in Photoshop which extracts all points in the green spectrum.

3.4.2 Hydrodynamic Modelling

Hydrodynamic simulations were carried out with the help of hydraulic engineers in the team using 2dMb. Here, the surface flow is computed based on the full depth-averaged shallow water equation and employs a finite volume scheme over a structured grid with explicit time discretisation. Details about the hydrodynamic model is further described in another publication (Lin et al. 2016).

3.4.2.1 Model Setup

Instead of having the scenarios produced as maps in the typical 2D GIS platforms, having it represented as point clouds allows for proposed changes to the river profile to be accurately modelled in 3D and embedded into the base point cloud model (Fig. 3.20). This technique was used to create scenarios seen in chapters 4.2 to 4.4 and the modified point cloud model with its new river profile and changes to the land use classification are then exported into a format for the hydrodynamic simulation.

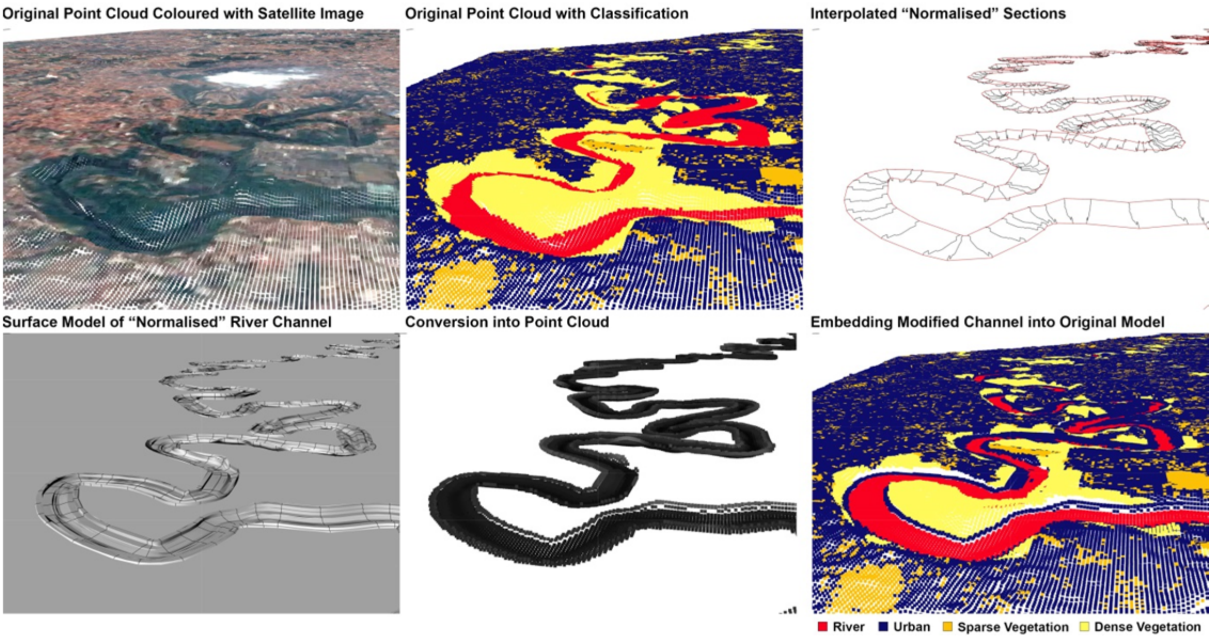


Fig. 3.20: The process of producing a modified point cloud includes modelling the proposed intervention creating new surface geometry, converting it into a point cloud and embedding it back into the original model.

For the initial site scale experiments with design-led scenarios generated by students (Chapter 4.2.2), point cloud models of each scenario were created but friction values were ignored and the flood wave consisted of a synthetic flood representing a regular, low and high flow situation. For the corridor scale experiments however (Chapter 4.3), three land use and three design scenarios were developed with a total of six surface bathymetries derived for the hydrodynamic model runs. In each case friction is modelled based on the Chezy formulation fitted to a logarithmic profile, for which Nikuradse's equivalent sand roughness coefficient is used as the input parameter. The values are derived from literature (Chow 1959) and assigned to different land use classification as tabulated in the Table 3.5.

Table 3.5: Nikuradse's equivalent sand roughness coefficient

Classification	**Friction**
River Class	0.10
Urban Class	0.01
Sparse Vegetation Class	0.15
Dense Vegetation Class	0.25

3.4.2.2 Initial and Boundary Conditions for the River Corridor Scale Simulations

Initial conditions for each corridor scale simulation were derived by using a constant inflow of $10m^3/s$ upstream and overflow weir downstream till the system reaches steady state. Outflow for all cases was modelled as an overflow weir at the downstream end assuming that the canal system downstream of Mangarrai barrage is able to remove most of the incoming discharge with little backwater effect. Currently no dynamic elements (e.g. pumping and operation of gates, etc) are introduced as part of the hydrodynamic modelling. Two flood events were modelled for each of the 6 scenarios – with inflow boundaries derived from two different methods and representing two different conditions (described in the paragraph below). It is noted that the inflow in both cases is introduced only at the upstream end while contributions along the 40km length (lateral inflow) is not explicitly accounted for.

Of the two events considered, the first inflow is based on the synthetic discharge hydrograph generated from rain fall by using the Nakayasu Synthetic Unit Hydrograph Method - One of the approaches used by the BBWSC (Balai Besar Wilayah Sungai Ciliwung-Cisadane), Ministry of Public Works (Indonesia) for designing flood control infrastructure. The hydrographs are provided by the BBWSC with calculations based on rainfall data measured from 1998 to 2007 (BBWSC, Personal Communications). The hydrograph used for the simulation is derived from 2 year return period of rainfall (based on the 10 years observed data) – representing a moderate and fairly recurrent event for the river system. The duration of this event is 70 hours. The inflow boundary has been calculated with Tol T.B. Simatupang as the outflow point for the parameterisation of the Nakayasu method.

The second inflow is obtained from a physically based hydrological model, TOPKAPI-ETH (Fatichi et al. 2014) setup and calibrated for the Ciliwung River system (Remondi et al. 2015). From the hydrological model, the inflow hydrograph for the 2007 flood event is derived, which represents one of the most extreme floods seen by Jakarta in recent years. The simulation of the 2007 flood event covers the main 5 days of the flood event – spanning a total of 105 hours. Results comparing our 5m resolution 2dMb simulation and the flood outline for a 2007 'like flood event' results at 50 m resolution obtained from InaSAFE (http://inasafe.org/en/) shows that our model is able to perform well when used as the base to generate the expected behavior of the river when compared to the existing flood model of the 2007 flood (Fig 3.21).

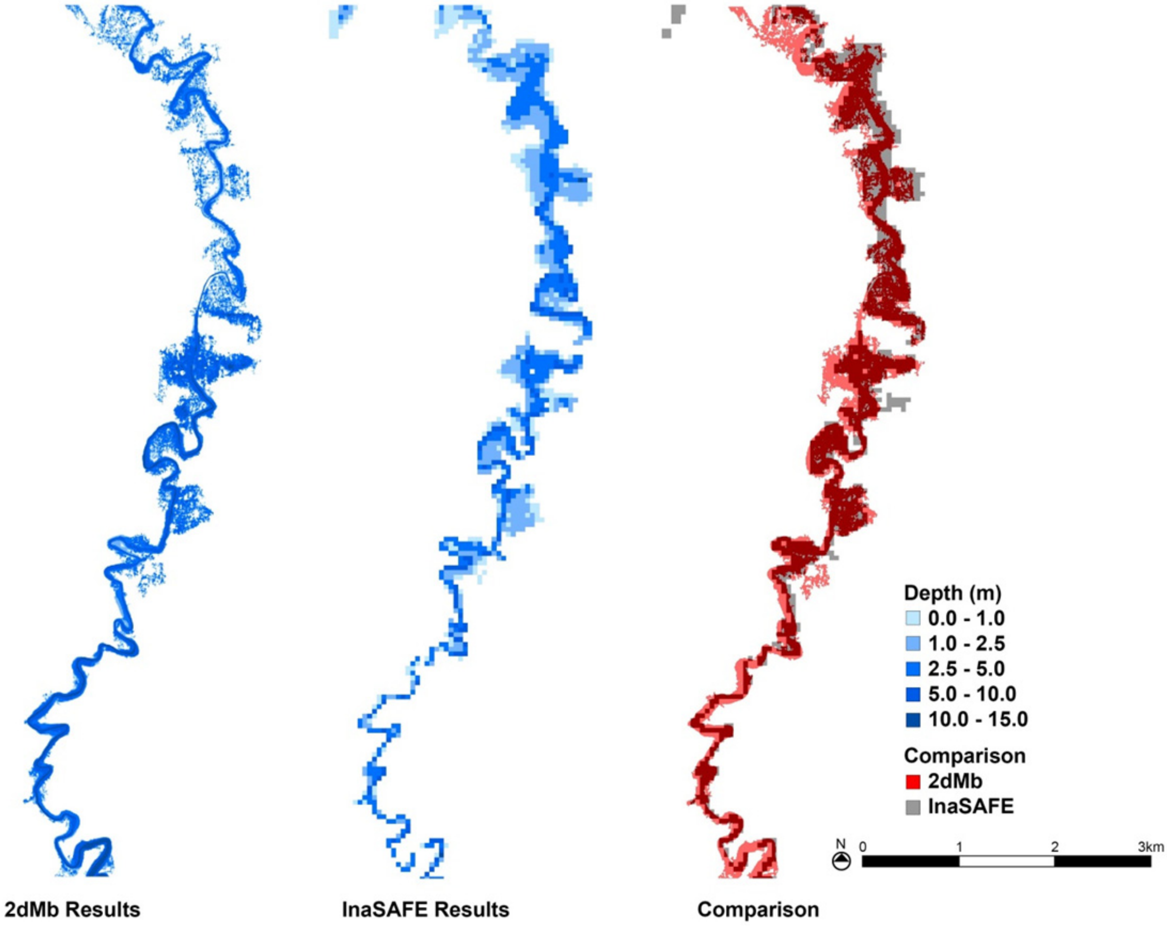


Fig. 3.21: 2dMb numerical model result showing depths at peak flood inundation for the 2007 flood model over base terrain model at 5m resolution compared against maximum depth of Jakarta 2007 flood obtained from InaSAFE maintained by AIFDR (Australian-Indonesia Facility for Disaster Reduction).

3.4.3 Landscape Metrics

Other than the flood simulations, another form of quantitative analysis employed by the thesis was the use of landscape metrics. Landscape metrics as landscape indicators falls broadly into four categories: (1) evaluation of land use/cover patterns or changes, (2) habitat functions, (3) regulatory functions, (4) information functions (Uuemaa et al. 2013b). Habitat and information functions are not possible to deduce without further on site investigations, as such this subchapter seeks to address the use of landscape metrics in relation to an evaluation of changes in land use/cover patterns and the potential resultant flood regulatory functions. The goal here is to find possible correlations between changing land use patterns and flood mitigation potentials obtained from the hydrodynamic simulations.

3.4.3.1 Exporting of Point Cloud Data into FRAGSTATS

Similar to the hydraulic simulations shown, the tools developed in Grasshopper allow for point cloud data to be exported into a format suitable for use in FRAGSTATS - which requires that the grids to be analysed must have a metric projection (e.g. UTM). FRAGSTATS allows for several forms of input data, the easiest format being an ASCII grid with each record containing a single image row with cell values separated by a comma or a space. An ASCII file requires 3 values; X, Y coordinates and a cell value, for FRAGSTATS this is a numerical class value indicating the relevant classification for every grid point. Since the point cloud is already coloured differently after the classification step, for simplicity sake we utilise the R channel in Rhinoceros's point cloud attributes (Fig. 3.22). After defining the required parameters, the exporting tool then simplifies the point cloud into a regularly spaced user defined grid and includes the option of including a border around the study area. The resultant classified point clouds are exported as an ASCII file at 1m resolution into FRAGSTATS for further comparative analysis.

Fig. 3.22: PCexportASC allows the user to export the RGB or UVW metadata values as cell values in an ASCII file. This workaround allows the user to classify the point clouds based on colours and export them accordingly as a cell value in the ASCII file. Care are needs to be taken at this point to ensure that the R values differ between the different classes in the point cloud model.

3.4.3.2 Running Models through FRAGSTATS

Running the categorised models through FRAGSTATS is a relatively straightforward task once the ASCII file has been properly exported from Rhinoceros. Using the raw ASCII input format in FRAGSTATS, the files were added as layers using information from the header of the ASCII files (Fig. 3.23). Alternatively the ASCII files can also be loaded into ArcGIS and exported as a GeoTIFF file or other suitable format.

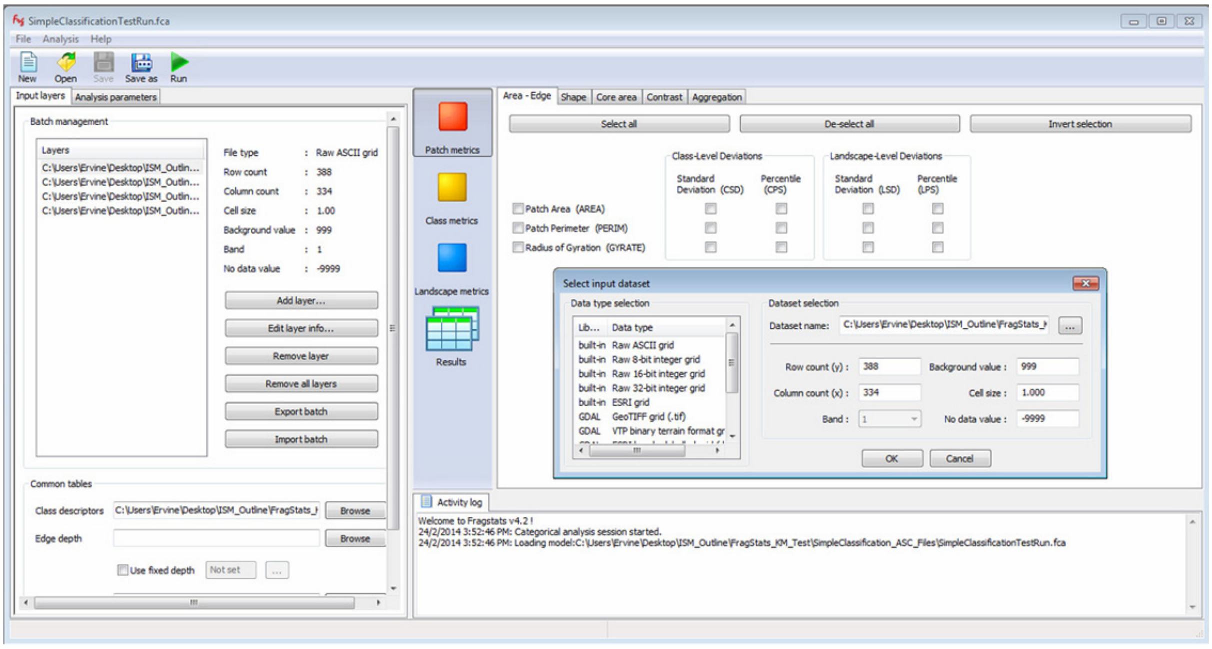


Fig. 3.23: The exported ASCII files were loading into FRAGSTATS as layers to allow for calculations to be run simultaneously across all the files. The input data necessary to generate the layers is available from the header of the ASCII file.

Two additional files were generated manually, a class descriptor file (to name the classes) and an edge contrast file (required specifically only for the Edge Contrast (ECON) metric) (Table 3.6). Metrics were calculated at the class and landscape levels. In addition, the selected metrics also had their related metrics calculated, namely area weighted mean, range and standard deviation and the results were saved and converted into CSV files to be worked on in Microsoft Excel.

Table 3.6: An example of the class descriptor and edge contrast files that need to be manually generated for the analysis of exported ASCII files in FRAGSTATS.

Class Descriptor File Details	**Edge Contrast File Details**
ID, Name, Enabled, IsBackground 3,Vegetation,true,false 1,OpenSpace,true,false 2,Urban,true,false 4,Water,true,false	FSQ_TABLE CLASS_LIST_LITERAL(OpenSpace, Urban, Vegetation, Water) 0,0.2,0.4,1 0.2,0,0.8,1 0.4,0.8,0,0.8 1,1,0.8,0

3.4.3.3 Metrics to be Calculated

A set of ten core landscape metrics were chosen which have been extensively explored and explained (Leitao et al. 2006). These ten (Table 3.7) include, Patch Richness (PR), Percentage of Landscape (PLAND), Number of Patches (NP) & Patch Density (PD), Mean Patch Size (AREA_MN), Shape (SHAPE), Radius of Gyration (GYRATE), Contagion (CONTAG), Edge Contrast (ECON), Euclidean Nearest Neighbour Distance (ENN) and Proximity (PROX).

Table 3.7: The list of selected metrics performed, their corresponding units and a description of the statistical information they portray of the landscape.

Metric	Description
Patch Richness (PR) *Unit: N.A.*	Provides the total number of different classes in a given landscape. Can be used as an initial measure of landscape diversity which is an indicator of greater biodiversity. However since classes are usually operator determined, this does not always provide useful comparative information especially so for the examples explored here whereby the number of LCTs is predetermined.
Class Area Proportion (CAP) & Percentage of Landscape (PLAND) *Unit: Ha (CAP)* *Unit: % (PLAND)*	Calculates the area (CAP) and proportion (PLAND) of landscape covered by a particular class. The CAP or PLAND is possibly the single most important landscape descriptor as it helps identify the existence and identity of the matrix in a landscape (the predominant class comprising of >50% of the landscape) as well as helps identify at risk or rare classes.
Number of Patches (NP) & Patch Density (PD) *Unit: N.A.(NP)* *Unit: Patches/100Ha (PD)*	NP counts the total number of patches. PD calculates the number of patches per 100ha. NP and PD are used as a measure of landscape configuration dealing with the degree of subdivision of the class or landscape, i.e. a higher NP or PD might indicate fragmentation
Mean Patch Size (AREA_MN) *Unit: Ha*	Calculates the average size of patches of a particular class. Patch size affects biomass, primary productivity, nutrient storage, species composition and diversity, etc. As such AREA_MN can serve as a rough indicator of landscape function. Coupled with other metrics, it can serve as a measure of the subdivision of the class or landscape, i.e. a small AREA_MN but with a large CAP can suggest that the class is fragmented.
Shape (SHAPE) *Unit: N.A.*	Provides an indicator of the geometric complexity of a patch. Simple shapes have SHAPE values close to 1.0; more complex shapes have higher SHAPE values. SHAPE is a measure of landscape configuration expressed as the ratio of the patch perimeter to the perimeter of the most simply-shaped patch within the same area (as such it is size independent). The geometric complexity of a patch influences the magnitude and nature of the interaction of a patch with its surroundings due to edge or cross boundary effects.
Radius of Gyration (GYRATE) *Unit: Meters*	Calculates the mean distance between each cell in a patch and the patch centroid. Higher GYRATE values indicate more extensive patches. GYRATE is a measure of landscape configuration that deals with the spatial character of patches. It provides an indicator of patch extensiveness, i.e. the average distance an organism can move across the landscape while remaining within the patch. As such GYRATE can serve as an indication of the landscape "traversability" of organisms confined to a single patch
Contagion (CONTAG) *Unit: Percent*	Quantifies the degree to which patches are clumped in a given landscape. Higher CONTAG values indicate that patches are more aggregated. CONTAG is a useful metric to quickly but broadly characterise a landscape pattern with a single value. As such it is useful when utilised as a comparative metric between landscapes or the same landscape over time. CONTAG is widely used in landscape ecology as it provides a description of landscape texture; the clumpiness or aggregation of classes.
Edge Contrast (ECON) *Unit: Percent*	Measures of the amount of contrast between adjacent classes. Higher values of ECON indicate higher contrast between adjacent patches. Patch edges play an ecological role in the movement of plants, animals, people and nutrients across the landscape. ECON is a measurement of the functional edge based on pre-determined contrast weights. As such this requires a clear understanding of the specific processes that are of interest to the investigator. ECON can provide an indication of how important a role edge contrast may be playing in a landscape (e.g. if it is not even present, it doesn't play much of a role). It can be used to test if recreational or riparian corridors can act as buffers to reduce detrimental ECON between ecosystem patches.
Euclidean Nearest Neighbour Distance (ENN) *Unit: Meters*	Measures the shortest distance from one patch to another of the same class. Higher ENN values indicate that the patches are more isolated from one another. ENN deals with relative locations and arrangements of patches in a landscape and describes the distribution of classes across a landscape. ENN aids the investigator in accessing how a particular landscape may function with regard to movement of people and wildlife, the spread of diseases, and other processes involving movement between patches of the same class. ENN can be used to study any phenomena in which distance between patches is important, such as the distance between recreational patches.

Proximity (PROX) *Unit: N.A.*	A unitless measure of patch isolation that includes information on size and distance of like patches from a specified "focal patch" within a given search radius. Higher PROX values indicate more aggregation or less isolation. PROX allows a means to quantify the spatial distribution of specific patch types across a landscape. As PROX is unitless, its main use is for comparative analysis where the direction and magnitude of change provides an indicator as opposed to the absolute PROX value, such as the changes in PROX values over a given time period.

3.4.3.4 Example of Applying FRAGSTATS to Measure the Differences between Two Sites

Landscape metrics are particularly useful when doing comparative analysis, either a before and after analysis or a comparison between sites. Here the thesis takes classified information from the downstream Kampung Melayu/Bukit Duri site and the midstream Tanjung Barat site and runs the two models through FRAGSTATS to identify any underlying structural differences between the two sites which cover an area of 450-500ha each at the same horizontal resolution of 1m. As per the classification method described earlier (Chapter 3.4.1), colour information from the orthophoto was used to extract the vegetation, manually drawn outlines for the river and water bodies and the final remaining urban fabric was separated according to height (Fig. 3.24).

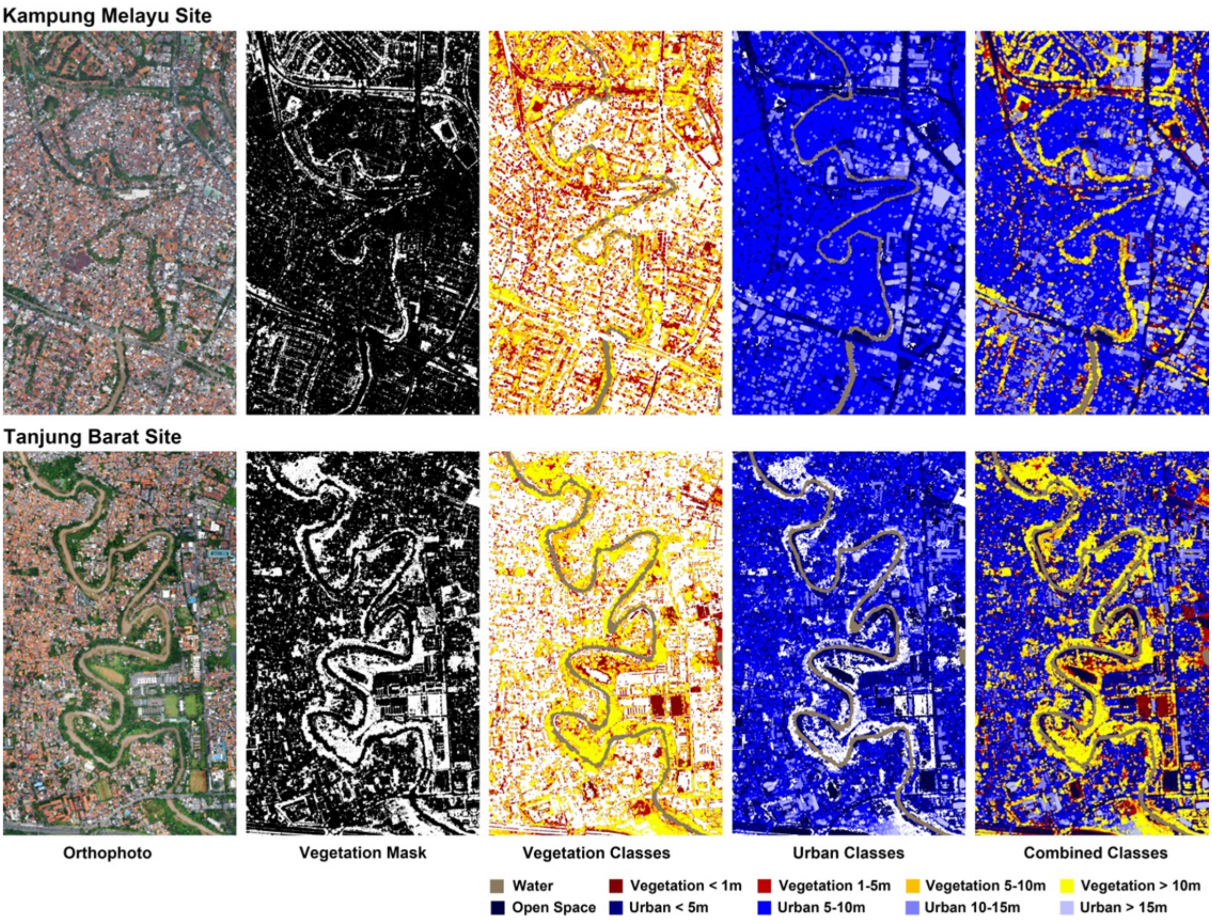


Fig. 3.24: The same methods and tools were used to classify two larger sites, the downstream "Kampung Melayu/Bukit Duri" site (500Ha), as well as a slightly more upstream "Tanjung Barat" site (450Ha). The maps above show, from left to right, the original coloured orthophoto, mask of vegetation created using Photoshop, vegetation points extracted and classified by height, classified urban points and final classified point cloud with 10 LCTs.

The most obvious difference upon visual inspection of the classification maps shows that the Tanjung Bahrat site appears to have more “vegetation > 10m” LCTs, especially so along the course of the river. This visual analysis is backed up by results from running the models through FRAGSTATS (Fig. 3.25). Here we see that the percentage of landscape (PLAND) covered by the “vegetation > 10m” LCT is almost 4 times more than in the downstream Kampung Melayu site. Similarly, the total amount of vegetative cover is likewise more in the Tanjung Bahrat site. The next noticable difference is seen in the urban LCTs for which the Tanjung Bahrat site results show that there are fewer urban structures above 5m in Tanjung Bahrat. These two differences are expected considering the Tanjung Bahrat site is more sub-urban as compared to Kampung Melayu and as such, fewer tall buildings, more vegetation was expected and this has been proven so by the FRAGSTATS analysis.

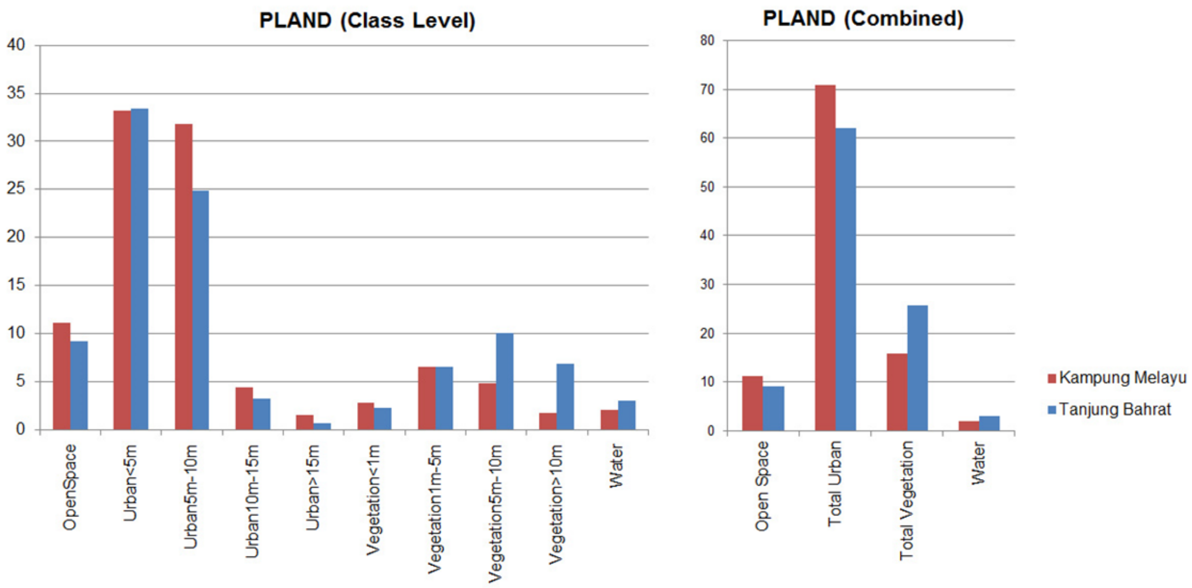


Fig. 3.25: Percentage of Landscape (PLAND) results of the two sites. PLAND (Combined) simply sums up all the urban and vegetation LCTs together to form a unified value.

Of the metrics that were calculated, the AREA_AM, GYRATE_AM and SHAPE_AM seemed provide the most reliable and expected results (Fig. 3.26). Here there are two noticeable LCTs which stand out from the rest, the first being the “urban < 5m” LCT which represents low buildings and structures. It is obvious from the results that firstly this LCT covers the largest percentage of the landscape (33%) in both sites. They also have a comparatively larger AREA_AM, GYRATE_AM and SHAPE_AM, indicating that the patches are generally larger, more extensive and have a more complex shape than the other LCTs. These values are higher in Tanjung Bahrat, suggesting that although it covers the same percentage of the landscape (PLAND), the “urban < 5m” LCT in Tanjung Bahrat is slightly more connected and extensive.

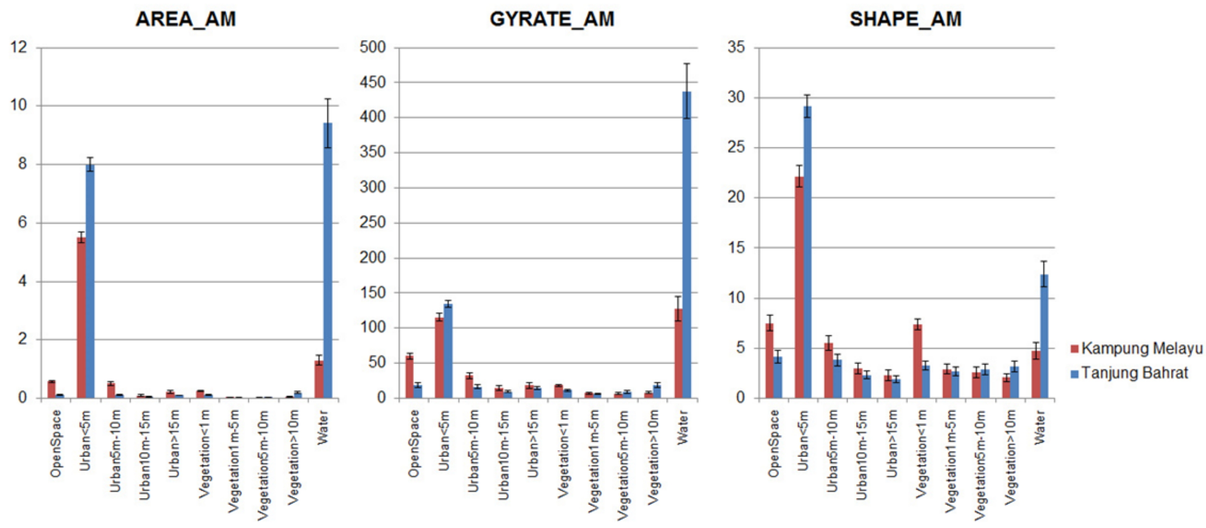


Fig. 3.26: Area weighted Mean Patch Size (AREA_AM), Radius of Gyration (GYRATE_AM) and Shape (SHAPE_AM) results of the two sites. Here the two most noticeable LCTs are the "urban < 5m" and the water LCTs.

Another noticable difference in Fig. 3.26 is in the water LCT. While we know for a fact that the river is not broken up and should be a single patch, occlusions by the surrounding vegetation in the Kampung Melayu site and the narrower width of the river break up this continuity. This issue is clearly visible in the difference between AREA_AM and GYRATE_AM values of the two sites. That said, when calculated without such occlusions (such as in the case of the Tanjung Bahrat site) the GYRATE_AM results suggests how the river can be used as a backbone for a continuous corridor, vegetated or otherwise, due to its extensive nature.

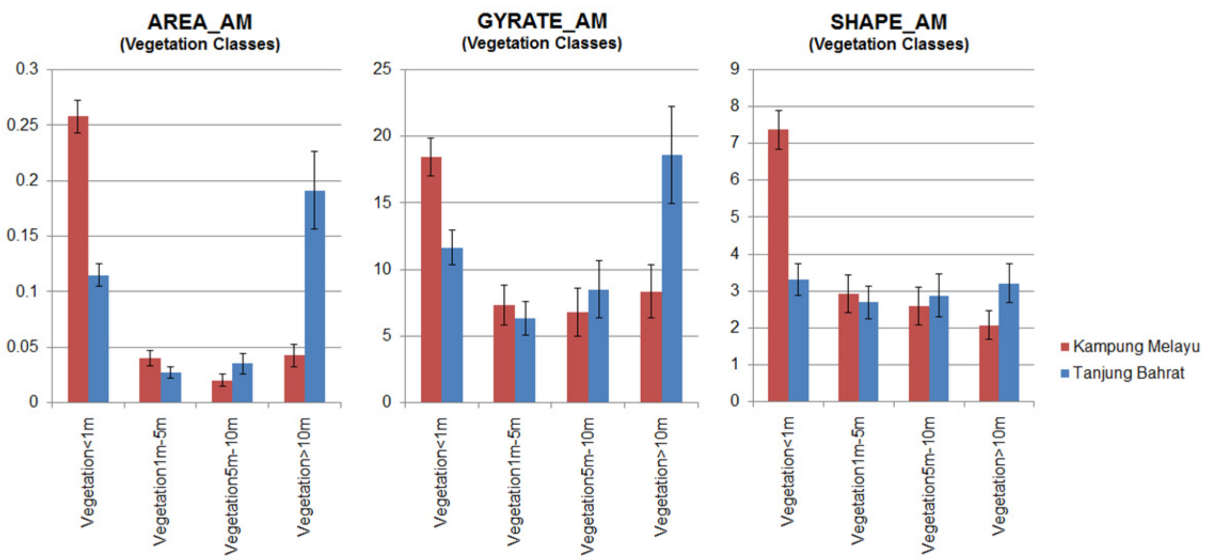


Fig. 3.27: Area weighted Mean Patch Size (AREA_AM), Radius of Gyration (GYRATE_AM) and Shape (SHAPE_AM) results of the vegetation classes of two sites. Here the most obvious differences are in the "vegetation < 1m" and "vegetation > 10m" LCTs.

When looking closely at the 4 vegetation LCTs of the two sites (Fig. 3.27). We see that Tanjung Bahrat does indeed have larger (AREA_AM) and more extensive (GYRATE_AM) "vegetation > 10m" patches (which would likely represent tall trees). Conversely, the Kampung Melayu site has larger and more extensive "vegetation < 1m" patches which might represent roadside planting, fields and graveyards which are found on the site. This again corresponds with what we know of the two sites as well as what is visible from the orthophotographs but adds a quantitative element to it for possible future analysis.

Some of the other calculated metrics need to be closely looked at to better understand them. For example, the ENN_AM (Fig. 3.28) results show that the average distance between patches of "urban > 15m" LCTs is the highest, that corresponds to a visual understanding of the site, whereby tall buildings are sparsely sprinkled over the landscape. However, the standard deviations for the ENN_AM are very high, which indicate a large variance across the patches. PROX_AM results prove to be problematic, it's unit-less nature, vast differences in values between LCTs and very wide standard deviations make it difficult to make sense of the numbers. Here if the PROX_AM values can be trusted, the "urban < 5m" LCT has the most aggregated patches; many fold more than any other LCT.

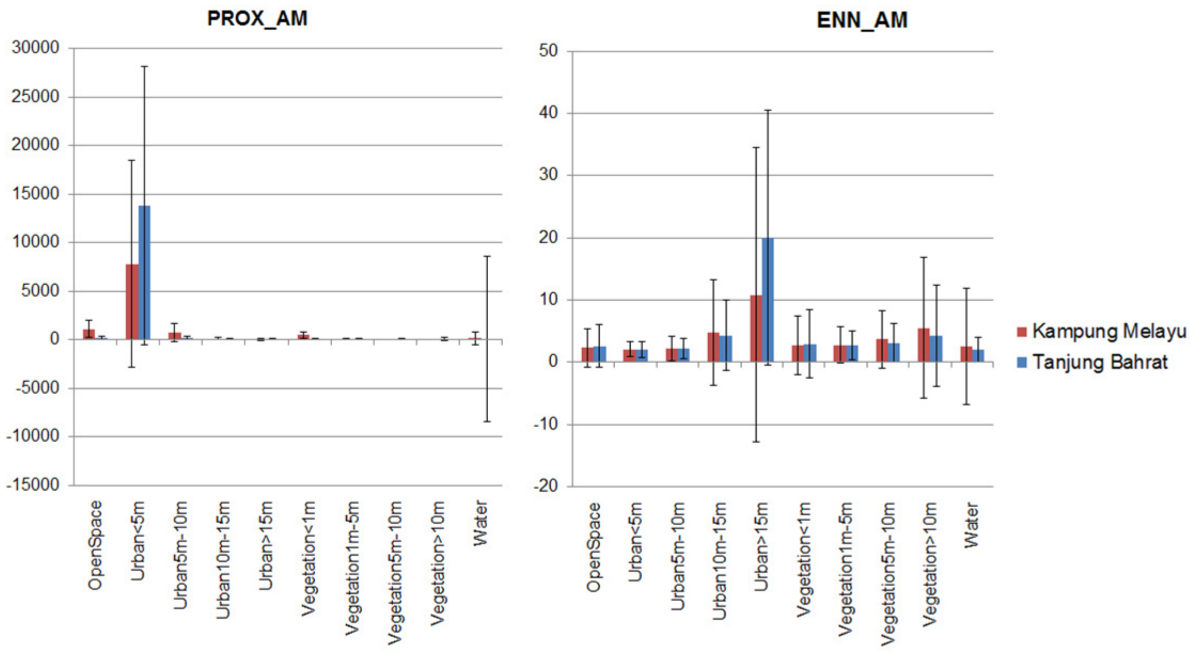


Fig. 3.28: Proximity (PROX_AM) and Area weighted Euclidean Nearest Distance (ENN_AM) results. ENN_AM while easy to interpret (Unit: meters) have very wide standard deviations, indicating that the distribution across the patches is very wide. PROX_AM results yield

Other metrics made little sense in calculating, the Edge Contrast (ECON) metric was left out of the calculations on purpose as ECON is meant to study a particular phenomenon that happens across different patches. Since there was nothing in particular to reference this to, arbitrary edge contrast values can be used but this in turn produces similarly arbitrary results which would yield no particular significance. Contagion (CONTAG) was also similarly difficult to compare with an arbitrary value of 46.9% for the Kampung Melayu site 43.1% for the Tanjung Bahrat site. CONTAG is measure of the degree to which patches are clumped in a given landscape, a higher value indicates more aggregation across all the classes in the landscape. In this case Kampung Melayu would be slightly more aggregated but not by much. This section has demonstrated the possibility of using point clouds for the calculation of landscape metrics to measure the differences between two existing sites, the same approach will be used to measure the differences between the corridor scale scenarios in chapter 4.3.6 to see if there are correlations between the metrics and the flood simulations results.

Chapter 4 – Scenario Development and Results

4.1 Overview

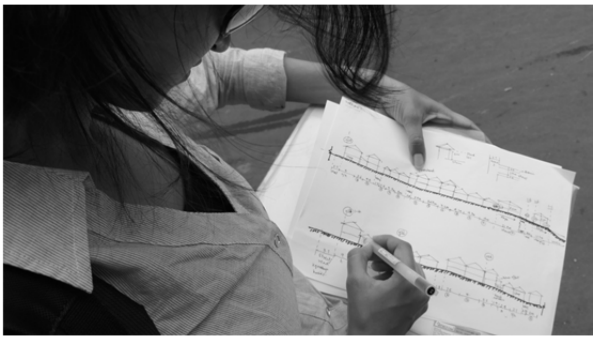
While the data was in the process of being obtained and the tools and workflows developed, a number of attempts were made by the project to develop scenarios to deal with the problems associated with the study sites. Design-led scenario developments were the first to be carried out whereby students situated within a design studio were tasked to come up with design solutions (Chapters 4.2.1 & 4.2.2). While the students operated only at the downstream Kampung Melayu/Bukit Duri site, a separated decision-led approach was carried out at the corridor scale to test the effectiveness of different overarching flood mitigation strategies (Chapter 4.3) from which the results from the hydrodynamic simulations and landscape metrics discussed (Chapters 4.3.5 & 4.3.6). The chapter rounds off with an attempt to utilise the data, tools and workflows developed in a real world setting (Chapter 4.4).

4.2 Local and Site Scale Design-Led Scenario Development

4.2.1 Local Scale Design-Led Scenario Developments

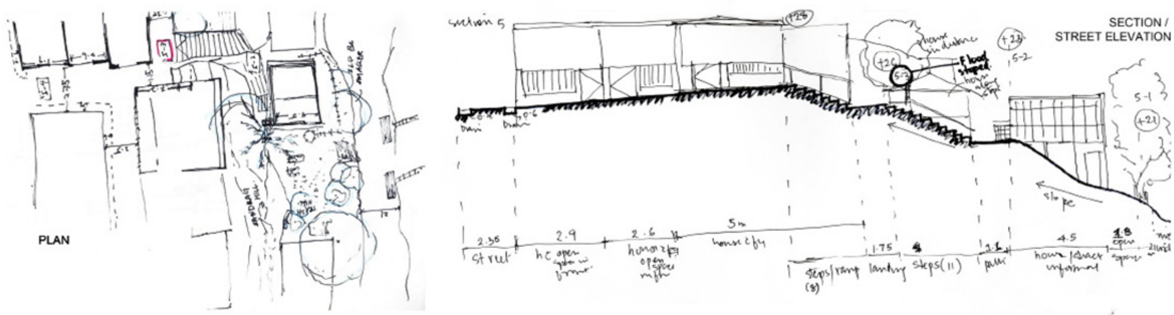
While we have established that the overarching project operates on three spatial scales - the site, corridor and catchment scales – and that the thesis mainly focuses on the first two, there is a subset of the site scale which some researchers in the group operate at, that is the local scale. This represents the spaces between and around the buildings, the alleys, roads and pockets of spaces invisible to the UAV due to occlusions from rooftops and tree canopies. It is at this scale which human interactions with the riparian landscape become immediately apparent. It is also the scale in which the process of "landing" (Girot 1999) occurs when students from the various Design Research Studios (DRS) first set foot into the downstream Kampung Melayu/Bukit Duri site. A total of 4 DRSs were carried out over the course of 2 years of which the first will be discussed here and the last in chapter 4.2.2. This first DRS carried out under the guidance of Assoc. Prof Dr Jörg Rekittke and Prof Christophe Girot saw 11 National University of Singapore (NUS) students from the Master of Landscape Architecture course try to tackle the multitude of issues plaguing the site (Girot and Rekittke 2012). The images found here in this section were obtained from the final presentation of the students' work (Rekittke et al. 2012a).

At this time, the students had no data from the UAV and had to rely on publically available terrain and satellite data or more often just their own manual methods of data collection and processing (Fig. 4.1). As such the approach the students developed and the eventual results can be used to form a meaningful comparison with the students from the last DRS which had full access to both the point cloud data as well as the tools developed to modify and test it.



Majority of the data was collected by hand, through on the ground measurements recorded with pen and paper.

One of the few technological gadgets the students had, a handheld Garmin GPS device, to help georeference some of their collected data.



An example of the sketches done in the field to collect spatial data of a particular identified section.

Fig. 4.1: Students from the first DRS had access to neither any of the UAV data nor the 3D point cloud models of the site, as a result they were tasked to record spatial data collected using manual means and recorded these measurements down in the form of sketches.

Due to the complexities on site, the labyrinth like network of streets and alleys and the constraints of time and manpower, the students decided on a sectional approach to studying the site in order to obtain precise samples along the riparian corridor. A total of 11 cross sections were identified and the students worked in teams to document the spatial qualities of these sites, appended to this were the approximate flood heights during a minor and major flood event obtained by interviewing residents who lived along these sections. With this manually collected data, the students eventually drew up detailed cross sections using a mixture of CAD and hand drawings (Fig. 4.2).

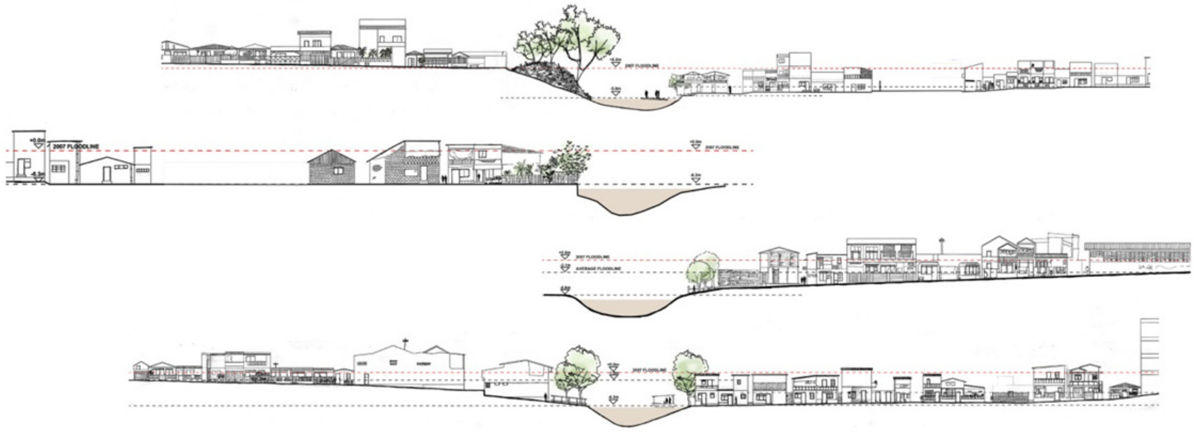


Fig. 4.2: An example of 4 of the 11 final sections produced by the students, each indicating the estimated flood level, based on interviews with local residents, during a minor and major flooding event.

While the sections were intended to provide a sampling of the conditions along the riparian corridor, relying solely on them eventually proved to be a great limiting factor when combined with the conflicting terrain data (Fig. 4.3). This meant that the students struggled to operate at a larger scale than what was immediately visible in their surveyed sections. The students termed this “sectional blindness” in which everything outside of the surveyed section was difficult to design for due to the lack of information.

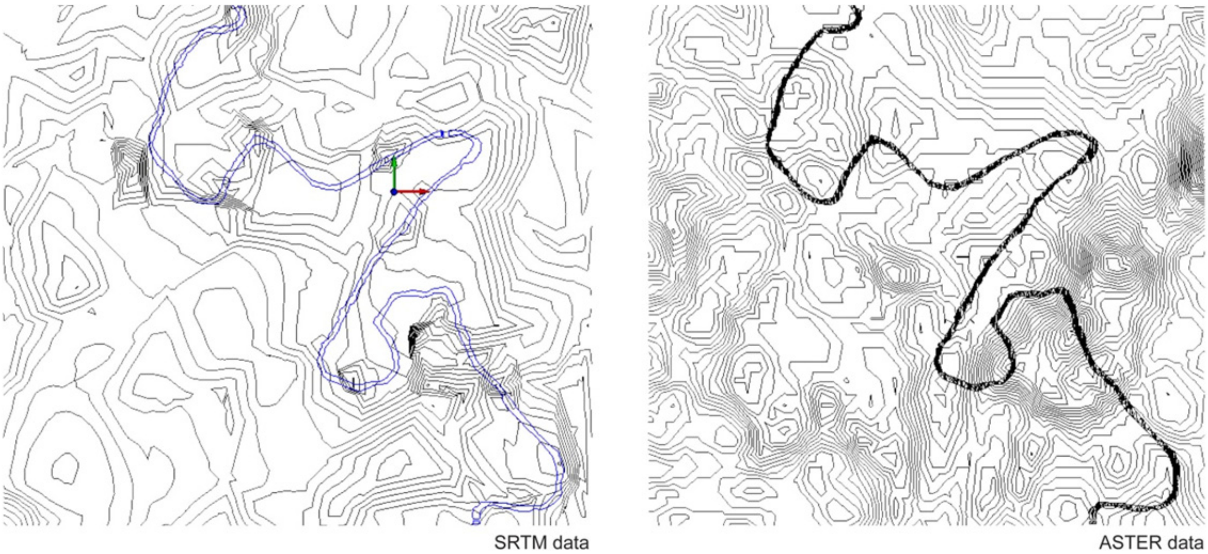


Fig. 4.3: The only available terrain data at that time were the Shuttle Radar Topography Mission (SRTM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) datasets, of which both not only exhibited serious flaws (e.g. river channel traversing up a hill) but were also contradicting each other.

Plans and 3D models of the site were created to try to fill in these gaps through the laborious and imprecise process of outlining and extracting building footprints using low resolution satellite imagery. Attempting to use these models to simulate floods proved to be a similarly coarse exercise as the flood simulation workflows were not yet developed and all that was available was the use of a single plane representing the approximated water level (Fig. 4.4).

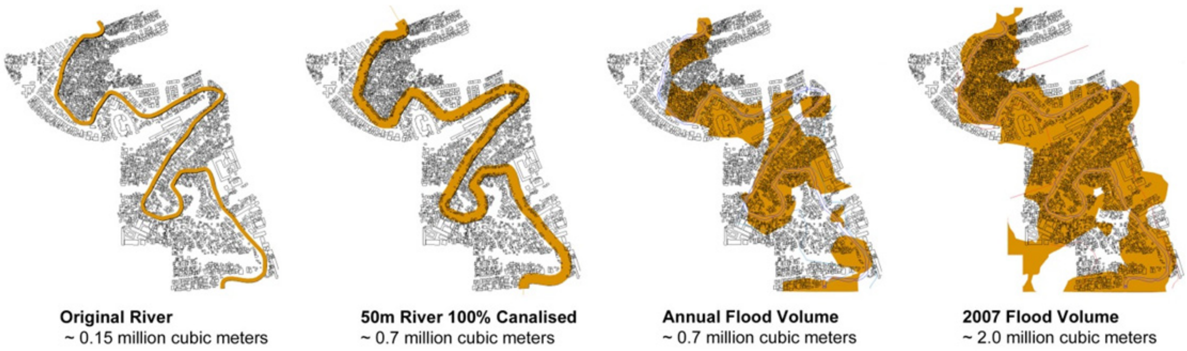


Fig. 4.4: Without access to proper flood simulation packages, the students could only approximate the effects of flooding over their site using a simple plane to represent the surface of the water.

As there was no way to directly address the floods due to the lack of proper flood simulations, the final outcome of this initial DRS was as a series of overarching suggestions for the river; bringing functions to the river to raise awareness of the river itself; fomalising connections across and along the river to enable it to function as mode of transportation; stabalising the banks using vegetation where possible to counter the plan to canalise the river; and the building of floodable parks and gardens along the course of the river to bring more recreational activities back to the river. These ideas were represented in the form of sectional drawings (Fig. 4.5) as well as presentation plans and perspectives (Fig. 4.6) created using a combination of 3D modelling, hand drawings and other "Photoshopped" techniques typical of perspectives today.

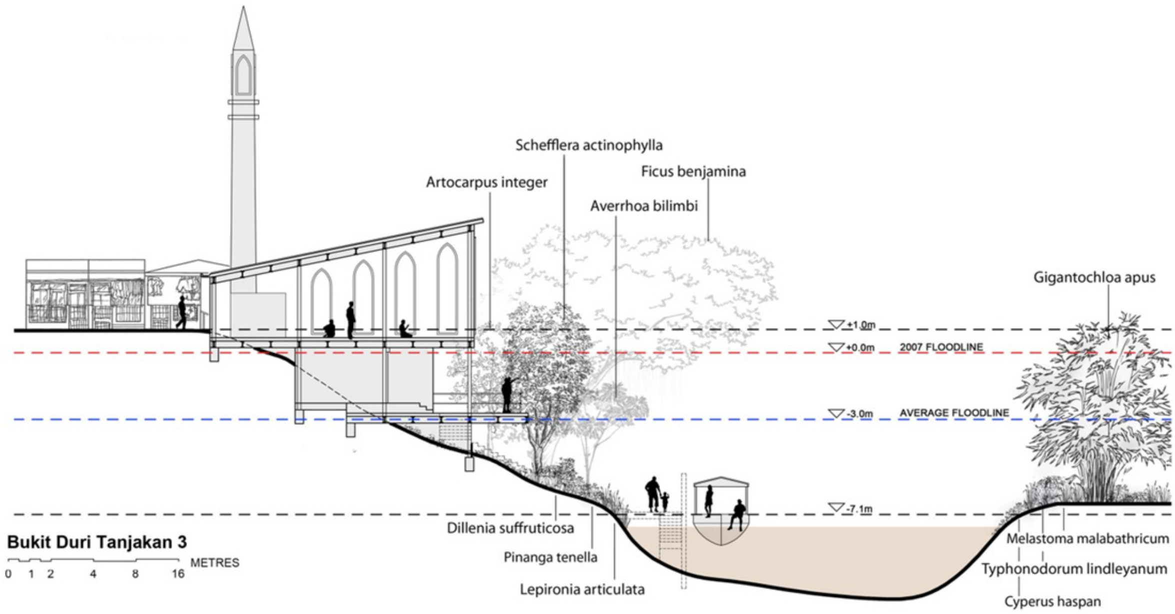


Fig. 4.5: An example of the proposed interventions, in this case a mosque along the banks of the river that is built clear of the estimated flood levels as well as flood resilient plants along the banks of the river.

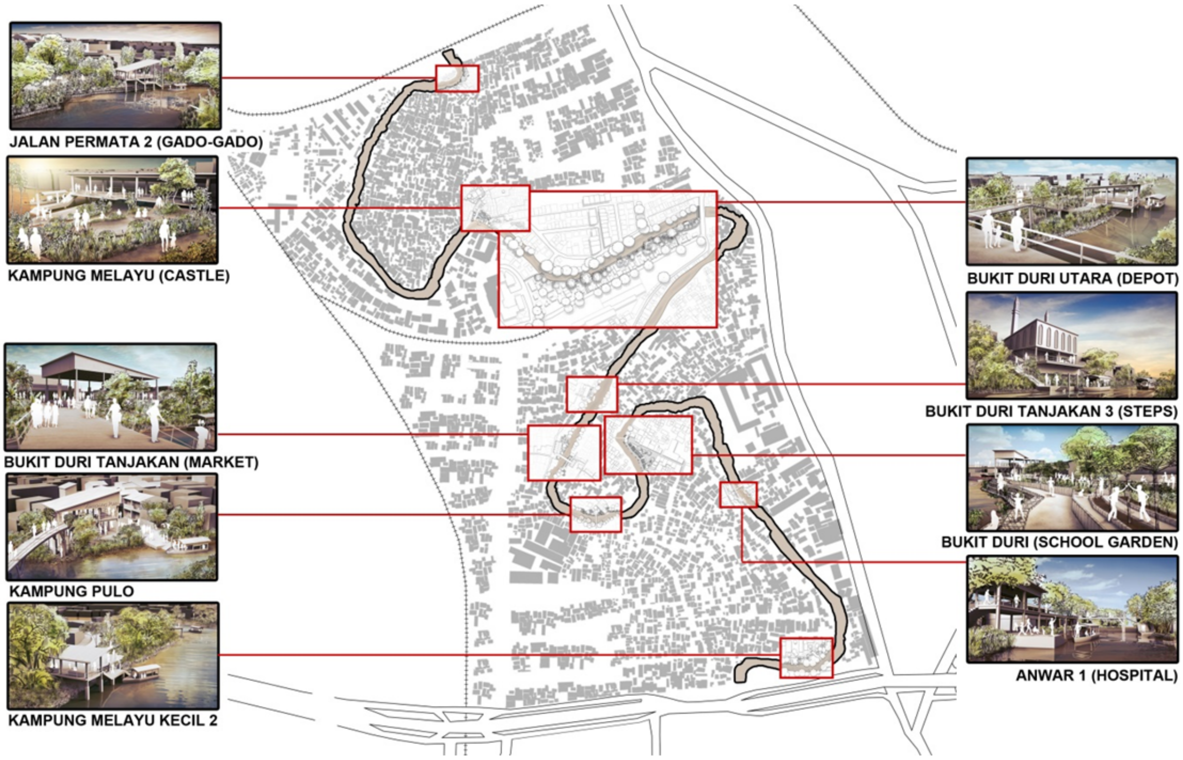


Fig. 4.6: The final outcome of the first DRS was the recommendations of small interventions scattered throughout the site represented in both presentation plans as well as perspectives.

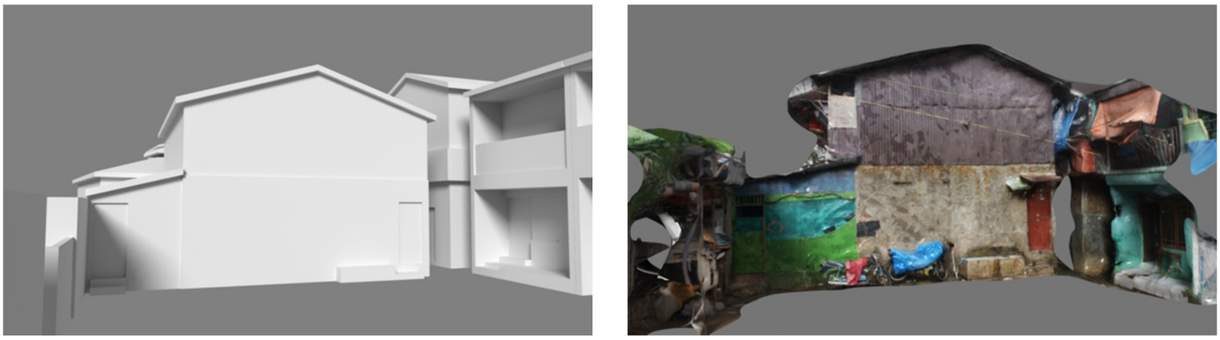
In all proposed interventions, the students found ways to live with the floods by raising important functional elements above the established maximum flood line (Fig 4.7) but were ultimately unable to develop convincing ways to mitigate the floods due to a range of limiting factors such as the lack of; accurate topographical data; proper tools and methods to perform simulations; data on both the upstream and downstream conditions of the site; and information about the exact causes of the floods. As such, while the DRS was concluded on a positive light considering the multitude of problems the students faced, there was a clear need to find ways in which designers can better survey and eventually modify the riparian landscape in order to more directly address the consequences of flooding and to find ways to reduce the impact on the residents along the river.

Perspective of a proposed prominently located community building to be built at the river's edge but with a flood resistant design.

A visualisation of a flooding event occurring in which the proposed intervention acts as a means for residents to cross the flooded river.

Fig. 4.7: The students proposed scenarios often consisted of elements which were designed to withstand a flooding event but not to mitigate the floods directly.

Other than the manual measurements and drawings done on site, the students also attempted to apply reality capture methods using the freely available Autodesk 123D Catch software (Rekittke et al. 2012b), unfortunately the results were often fragmented and were difficult to integrate into the existing models at hand (Fig. 4.8). Since then, other colleagues in the team have significantly improved these reality capture workflows (Rekittke et al. 2013a, 2014) and have been continually obtaining ever improving results with the latest field work including the use of a terrestrial laser scanner (Fig. 4.9).



Manually modelled buildings based on photographs and other measurement data collected on site.

Reconstructed 3D model of the same area using Autodesk 123D Catch.

Fig. 4.8: While the students experimented with reality capture during their field work, the results from these were very fragmented and often were not even successful after running the captured photographs through Autodesk 123D Catch.

It is clear that as the technology matures and becomes more readily available to end users, obtaining accurate spatial data using such tools becomes a very attractive alternative to the tedious and often inaccurate manual methods traditionally used by the students, especially so under such difficult conditions. To explore this possibility of using technology to obtain and work on this site, the thesis compares this DRS to the next group of students who similarly operated on the exact same site but were now armed not only with a point cloud model of the site obtained through a UAV campaign but also the tools and workflows to enable the injection and testing of their design ideas.

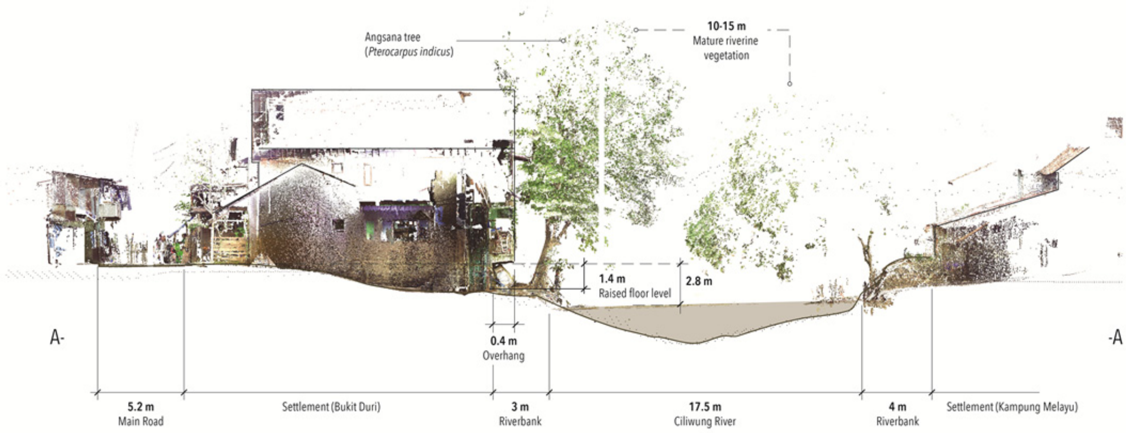


Fig. 4.9: The use of a terrestrial laser scanner brings a much higher degree of accuracy and coverage and allows researchers to make precise measurements and other inferences after the data has been collected (Prescott and Ninsalam 2016).

4.2.2 Site Scale Design-Led Scenario Developments

In March 2013, a week long international design workshop was facilitated by the Future Cities Laboratory (FCL) and involved 47 students and seven faculty members from four institutions. This included 22 students from the Swiss Federal Institute of Technology in Zurich (ETHZ), nine students from the National University of Singapore (NUS), 10 students from the University of Indonesia (UI) and six students from Bogor Agricultural University (IPB). The workshop was initiated by Professor Christophe Girot, Principal Investigator of FCL's Landscape Ecology research module. He was supported by Associate Professor Dr Jörg Rekittke from the Department of Architecture at NUS, Professor Herlily from the Department of Architecture at UI, and Professor Dr Hadi Susilo Arifin from the Department of Landscape Architecture at IPB.

The workshop - once again focused on the downstream Kampung Melayu/Bukit Duri site - aimed to discern the present situation of the river, and to develop a set of alternative proposals that take into account flood risk, together with opportunities for urban and landscape change. It began with a site visit in Jakarta where students from the various universities were divided into small groups and given specific areas to study marked out by high resolution orthophotographs and maps made available through the UAV data collected (Fig. 4.10). They investigated, discussed and worked intensively with each other over three days and presented their fieldwork to local architects, NGO's and university faculty in Jakarta. Work then continued in Singapore at the Singapore-ETH Centre (SEC) where the students further develop their ideas and resolve design scenarios. The final review of the design scenarios was held before students returned to their home institutions with students from the NUS and ETH each continuing as part of the final DRS which worked on the Ciliwung River.

Students were handed high resolution orthophotographs of their respective study areas.

Maps were similarly provided for the students to work directly off.

Fig. 4.10: While students from the first DRS had only low resolution data to work off, students from the international design workshop had the luxury of access to high resolution orthophotographs and maps derived from the UAV data.

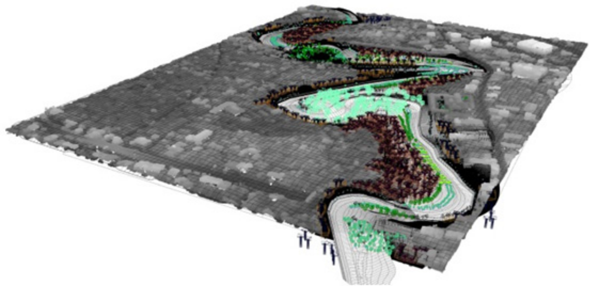
While provided with high resolution maps, the outputs of the workshop were understandably still two dimensional in nature owing to the lack of time and access to computers during the workshop. As a result, the students' final presentations consisting mainly of preliminary plans and sections of proposed scenarios (Fig. 4.11). However, even as the students returned to their home institutions to further flesh out their designs, there was a preference to stick to typical plans, sections and "Photoshopped" perspectives built up from 3D block models instead of reality captured point cloud models (Fig. 4.12).

Fig. 4.11: Groups of students presented their final designs at the Singapore-ETH Centre's Valuelab. Understandably due to the time constraints, designs were primarily 2 dimensional in nature without any possibility of quantitative analysis.

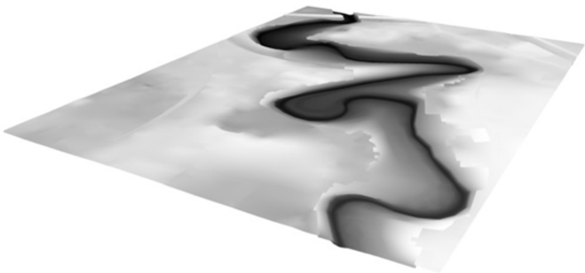
Fig. 4.12: An example of a typical plan, section and perspective output from the students after returning to the ETH Zurich (Lorraine Haussmann & Kylie Russnaik 2013).

To further push the students into adopting a point cloud workflow for the purposes of testing their designs with a flood simulation, an additional elective was held for the ETH students in collaboration with instructors at the Landscape Visualising and Modelling Laboratory (LVML) at the ETH Zurich (Girot and Melsom 2014). In this elective, students were provided with the processed 3D point cloud data of the site and taught specifically how to work with point clouds in Rhinoceros and Grasshopper using the tools developed as well as parametric tools created by a fellow researcher (Ninsalam 2014). Using these tools and methods, pairs of students could formulate and embed scenarios into the underlying point cloud model based on their initial design intentions (Fig. 4.13). Using the preliminary DTM created from the UAV data, a total of four different scenarios were generated, in which all the students were able to include a multitude of changes including changes to the width, depth and course of the river, modifications to the surrounding topography and urban fabric as well as the infrastructural additions like check dams. The goal here was to enable an iterative interface between their designed scenarios and the performative evaluation of these scenarios using flood simulations performed with the help of the team's engineers.

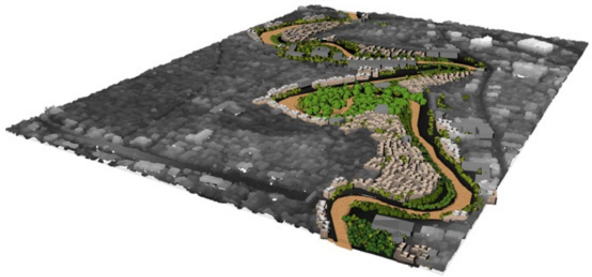
The original coloured digital surface point cloud model.



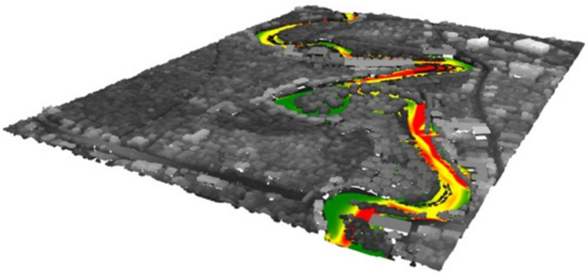
Using surface modelling techniques, the desired interventions can be modelled to be converted into point cloud models.



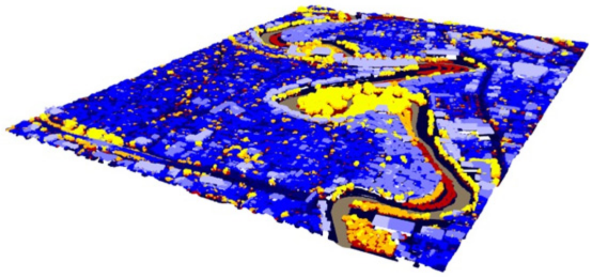
The river bathymetry is altered significantly to introduce a gentler slope along the banks and then merged back into the original DTM point cloud model.



A representation of the final scenario with a low flow event.



Other than just the extent of the flood, other factors such as the velocity can be visualised.



If so desired, the point clouds can also be classified and used in landscape metric calculations.

Fig. 4.13: An example one of the students' scenarios being represented entirely using point clouds instead of surface or mesh models as well the result of a flood simulation carried.

The results of these flood simulations, which indicate both a synthetic minor and major flood event, were produced in the form of maps and animations, cross referencing the designed scenarios against one another as well as the as-is state of the landscape (Fig. 4.14). These results included visualisations of not only the flood extent but also the velocity and depth indicators to serve as additional parameters to evaluate the flood mitigation potentials of the various scenarios. This was done as extent alone is not fully indicative of the potential damage a flood might bring as the depth of the flood might be so low as to be considered insignificant. Velocity might be useful to indicate areas which might require stronger bank stabilisation or reinforcement techniques to prevent erosion. These additional indicators obtained from the flood simulation results when visualised allows the designer to better understand the impacts their proposed interventions have with relation to the river dynamics.

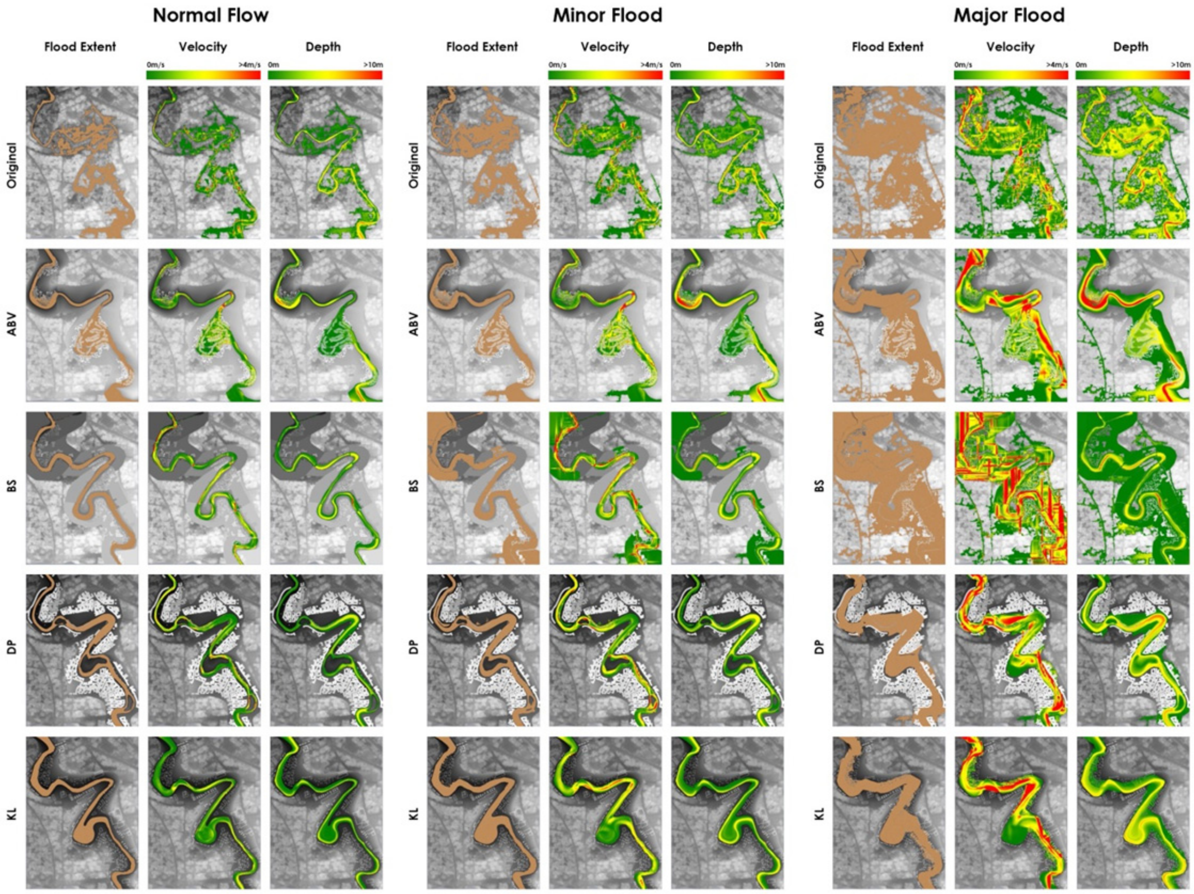


Fig. 4.14: A total of 4 scenarios together with the original scenario were tested with a flood simulation to compare the efficacy of each design with respect to its flood mitigation performance. In total, three different flood events were simulated, one which represented the rivers normal flow condition, another a minor flood and the last a major flood event. Other than the flood extent alone, velocity and depth maps were generated as well to provide more information about the flood propagation. (ABV – Anna Gebhardt, Basil Witt & Vladimir Dianiska, BS – Benedikt Kowaleski & Shoichiro Hasimoto, DP - Demajan Haller & Pascal Ryser, KL – Kevin Olas & Andreas Hani, 2013)

The experiment proved that the tools and workflows developed could indeed be handed over to young landscape architects and provide for the platform in which multiple alternative future scenarios are produced, hydraulically tested and their results visually compared against one another. While the results were indeed useful as an evaluative tool, here is also where caution needs to be exercised not to take these results as literal potential real world scenarios. While all the designed scenarios appear to have a positive effect on flood mitigation, the extent of modifications made to the landscape and urban fabric is immense. The scenarios generated by the students made extensive changes to river corridor and surrounding settlements in order to expand the width of the river to be able to contain the flood waters (Fig. 4.15). In this example it was calculated that 2.1 million cubic meters of earth needs to be excavated for this scenario to be realized. This combined with the sensitivity of evictions in Jakarta (Steinberg 2007) would seem to be make this an even more unviable option.

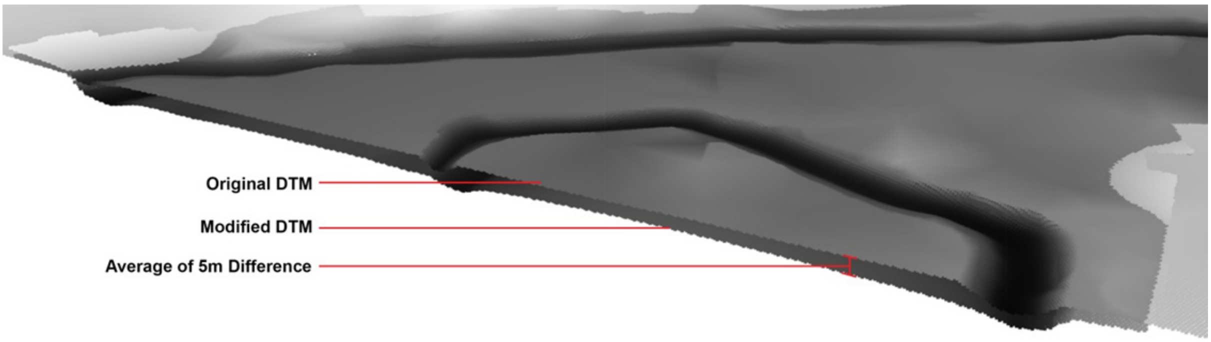


Fig. 4.15: A section through the original and modified DTMs reveals the extent of earthworks that need to be carried out in order to realise such a scenario. Here an average depth of 5m was excavated with a total of 2.1million cubic meters of earth excavated. While this is not impossible, doing this would require the eviction of tens of thousands of residents and businesses - something which is highly unlikely to happen.

The reason why such extensive modifications had to be made was because there was no other way to alleviate the flooding when only working on this downstream site in isolation. It is important to understand that river dynamics are never restricted to a single isolated stretch along the river and it is erroneous to think that any reasonable modifications to the river along this site alone will be sufficient to fully address the issue at hand. As such the thesis shifts its focus to the larger corridor scale to see if more extensive interventions along a longer stretch of the river will be able to provide a more realistic means to address the issue of flooding.

4.3 Corridor Scale Decision-Led Scenario Development

Based on the previous experiments, it is clear that the issue of flooding needs to be approached from a larger scale which allows for more space and time to control the incoming flood wave. As such this section details the work done on testing corridor scale decision-led scenarios. These decision-led scenarios differ from the design-led scenarios previously presented in that they are derived from choices made from the onset of preparing a scenario and not through the process of design exploration. A total of six scenarios divided over two sets were tested (Table 4.1). In ecological planning, hydraulic systems and the landscape relations that they create scenarios can play a key role in allocating land use (Ndubisi 2002) and similarly in reverse, changes in land use and topography along the riparian landscape directly affect these various systems. Thus the first set of scenarios was based solely on changes in land use, while the second set was based on topographical changes along the river corridor. In all of these scenarios, all infrastructure interventions were based on direct alternations to the river corridor rather than through operation and control of water via dams, gates, etc. It should also be noted that the following broadly defined scenarios are not based on any in-depth feasibility studies, instead they are derived from existing or proposed interventions with the focus on demonstrating a methodology rather than specific solutions. It is however envisioned that they prove helpful to give a broader insight into the possible remediation strategies available to deal with flood management.

Table 4.1: Corridor Scale Scenario Descriptions

No.	Scenario Abbreviation	Description
1	OR	Original river cross-section representing current land use
2	OR_U	Original river cross-section with a random reduction of current riparian vegetation replaced with an urban classification
3	OR_V	Original river cross-section with an increase in riparian vegetation along entire course of the river.
4	FN	Full normalisation consisting of a trapezoidal canalised river cross-section along the entire course of the river.
5	PN	Partial normalisation consisting of short segments of a traditional trapezoidal canalised river cross-section only along selected sections of the river.
6	GI	Green infrastructure scenario consisting of a multifunctional riparian corridor with ecological, recreational and flood mitigation functions in mind.

4.3.1 Land Use Change Scenarios (OR, OR_U, OR_V)

Riparian vegetation is part of the complex ecological dynamics which affect the flow, sediment transport and morphology of a river (Camporeale et al. 2013). The corridor scale scenario development begins with a baseline original scenario (OR) using the existing site condition represented as point cloud model and with land use classification embedded within it. As the degree of continuity of riparian buffers is crucial to water-filtering and habitat-producing ecosystem services , the next scenario is a hypothetical urbanised scenario (OR_U), which randomly reduces riparian vegetation along the corridor and replaces it with an urban layer. This is followed by a vegetated scenario (OR_V), which assumes that a landscape re-vegetation program would be carried out along the entire stretch of the river. The goal of these 3 initial scenarios (Fig 4.16) was to examine how the simulation would respond to changes along the riparian corridor and was not meant to represent possible real world possibilities such as in the following 3 scenarios FN, PN and GI. This when compared to infrastructural changes presented in the following scenarios will allow us to understand which changes would have a more noticeable effect in the simulation; changes in vegetation, in channel dimensions, or both.

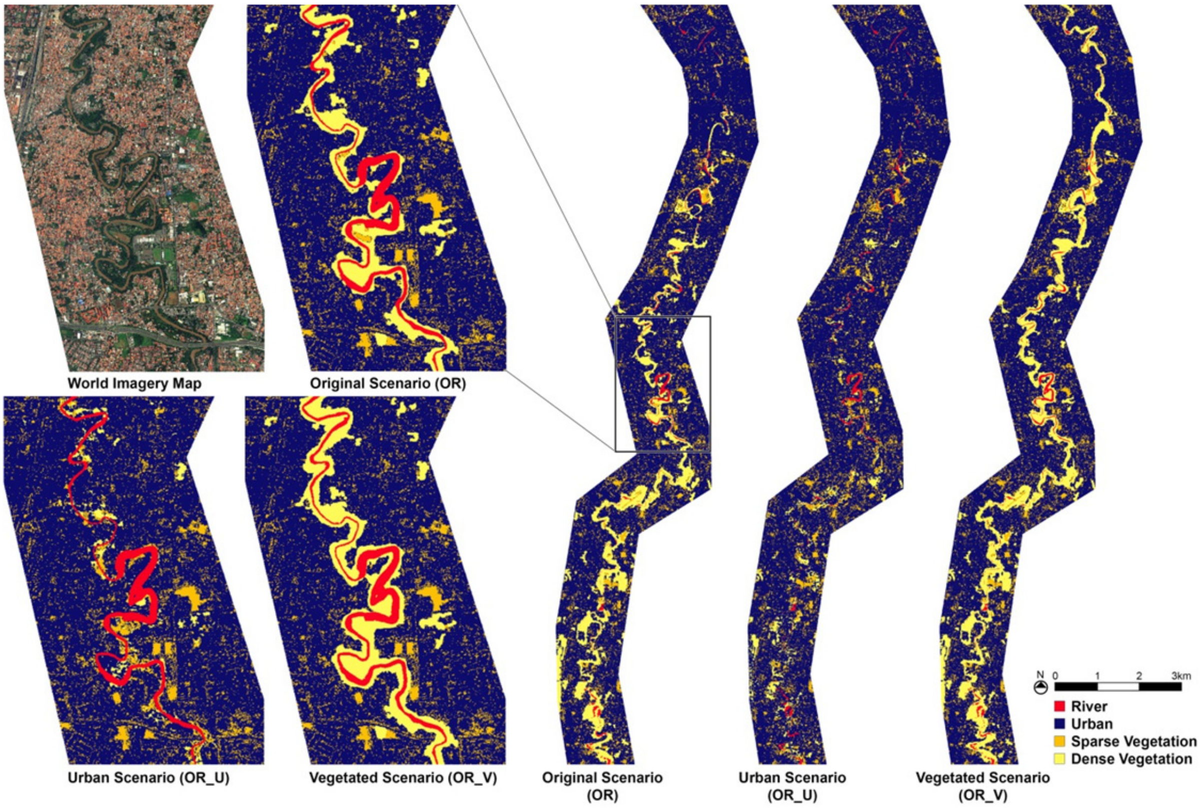


Fig. 4.16: Three land use change scenarios, original (OR), urban (OR_U) and vegetated (OR_V), with varying degrees of riparian vegetation were produced to test the results they have on the hydraulic simulations.

The degree to which these initial 2 variants were modified was quantified using FRAGSTATS measuring the total area and percentage coverage of each class (Table 4.2). For this section, only the basic Class Area (CA) and Percentage of Landscape (PLAND) metrics to compare the changes made to the different scenarios. The CA metric refers simply to the total area of each of the identified classes in the landscape (river, urban, sparse and dense vegetation classes) while the PLAND metric refers to the percentage of the total landscape covered by a particular class. The quantification of these two metrics across the developed scenarios is meant to facilitate the comparison between the changes in land use between the scenarios.

Table 4.2: Quantification of the three land use change scenarios. In these scenarios there were no topographical changes and the river class was left intact. The only change occurs in the land use classifications along the riparian corridor.

	Original Scenario (OR)	Urban Scenario (OR_U)	Vegetated Scenario (OR_V)
Total Area (km^2)	31.39	31.39	31.39
CA / Class Area (km^2) *- the total area of each class*			
River Class	1.44	1.44	1.44
Urban Class	23.17	24.96	22.31
Sparse Vegetation Class	3.43	3.86	3.31
Dense Vegetation Class	3.35	1.13	4.33
PLAND / Percentage of Landscape (%) *- the percentage of the total landscape covered by each class*			
River Class	4.60	4.60	4.60
Urban Class	73.81	79.52	71.08
Sparse Vegetation Class	10.91	12.29	10.54
Dense Vegetation Class	10.68	3.60	13.78
Percentage Change (%) *- the percentage change with respect to OR*			
River Class	-	0.00	0.00
Urban Class	-	+7.73	-3.70
Sparse Vegetation Class	-	+12.59	-3.41
Dense Vegetation Class	-	-66.31	+29.06

4.3.2 Full Normalisation Scenario (FN)

The second set of scenarios consists of a series of topographical changes along the river corridor, the first being a fully "normalised" channel which runs the entire length of the river, this normalisation of the river was a project led by the Ministry of Public Works which includes strategies to dredge the river, stabilise its banks and develop other flood mitigating infrastructures (Vollmer et al. 2013). Infrastructural modifications to the base point cloud model were derived from a report from the Ministry of Public Works (Spatial Planning and Design Details of the Ciliwung from upstream to the Manggarai Dam 2008) which details 700 cross sections of the proposed normalised channel. This included dredging, expansion and bank reinforcement works which would change both the topography and land use along the riparian corridor. Using this information, we were able to position the cross sections into the point cloud model, interpolate and embed them into the base point cloud model forming a continuous, approximately 50m, wide channel across the entire length of the river at this scale.

4.3.3 Partial Normalisation Scenario (PN)

The full normalisation is not expected to be carried out in its entirety considering the complications in land acquisition required to achieve this. As such the next scenario is one which better reflects what is interpreted as the more likely short term solution to be implemented, that is a partially normalised scenario. This is based on a an interpretation of the latest spatial plans ('Sosialisasi Rencana Detail Tata Ruang DKI Jakarta' 2013) combined with observations from the field as to how these improvements are being carried out (Fig 4.17). The main difference between these first two scenarios is that the latter assumes that the normalisation works are neither as extensive along the course of the river nor as across it. In addition, we included the diversion channels indicated in the plans which cut-off several meanders allowing for them to be filled up forming land for further urban development.

Fig. 4.17: Over the course of the project, piling works were continuously being carried out along sections of the river as part of the normalisation works planned (June 2013). The right most photograph shows an example of a normalised river.

4.3.4 Green Infrastructure Scenario (GI)

While the previous two scenarios would provide more space for the flood waters, the provision of recreational and ecological functions is clearly missing. It has been found that there is a significant demand for both park space and forest conservation from the urban residents of Jakarta (Vollmer et al. 2013) with preference towards a more ecologically-oriented rehabilitation plan (Vollmer et al. 2015b). In urban contexts such as these, riparian zones represent a loci for human-nature interactions which can provide a starting point for ecological and socioeconomic revitalisation (Groffman et al. 2003). The final scenario thus tests if an abstracted version of a multifunctional riparian green infrastructure designed with ecological and recreational functions in mind can also provide a reasonable degree of flood mitigation by building upon a strategy of providing more space for water, plants, animals and people (Prominski et al. 2012).

Instead of routing flood waters through as quickly as possible, here the strategy is to retain and store incoming flood waters thus possibly moderating the effects further downstream. This is achieved by cross referencing the original flood results together with the underlying topography of the base point cloud data to identify areas where potential retention basins can be created or where the river might be allowed to expand in times of flooding (Fig 4.18). These areas are then classified abstractly as vegetated areas which indicate either floodable parks or forested conservation areas while any proposed river expansion is dealt with vegetated slopes instead of vertical concrete piles thereby conferring a more natural character to the river.

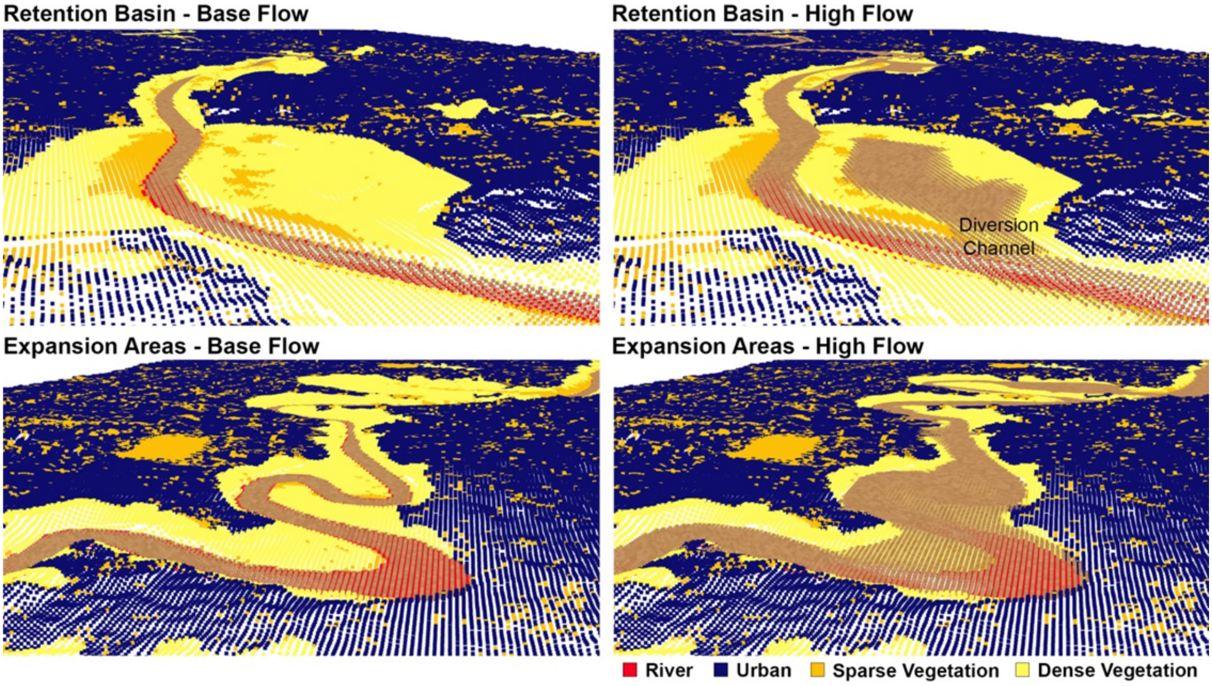
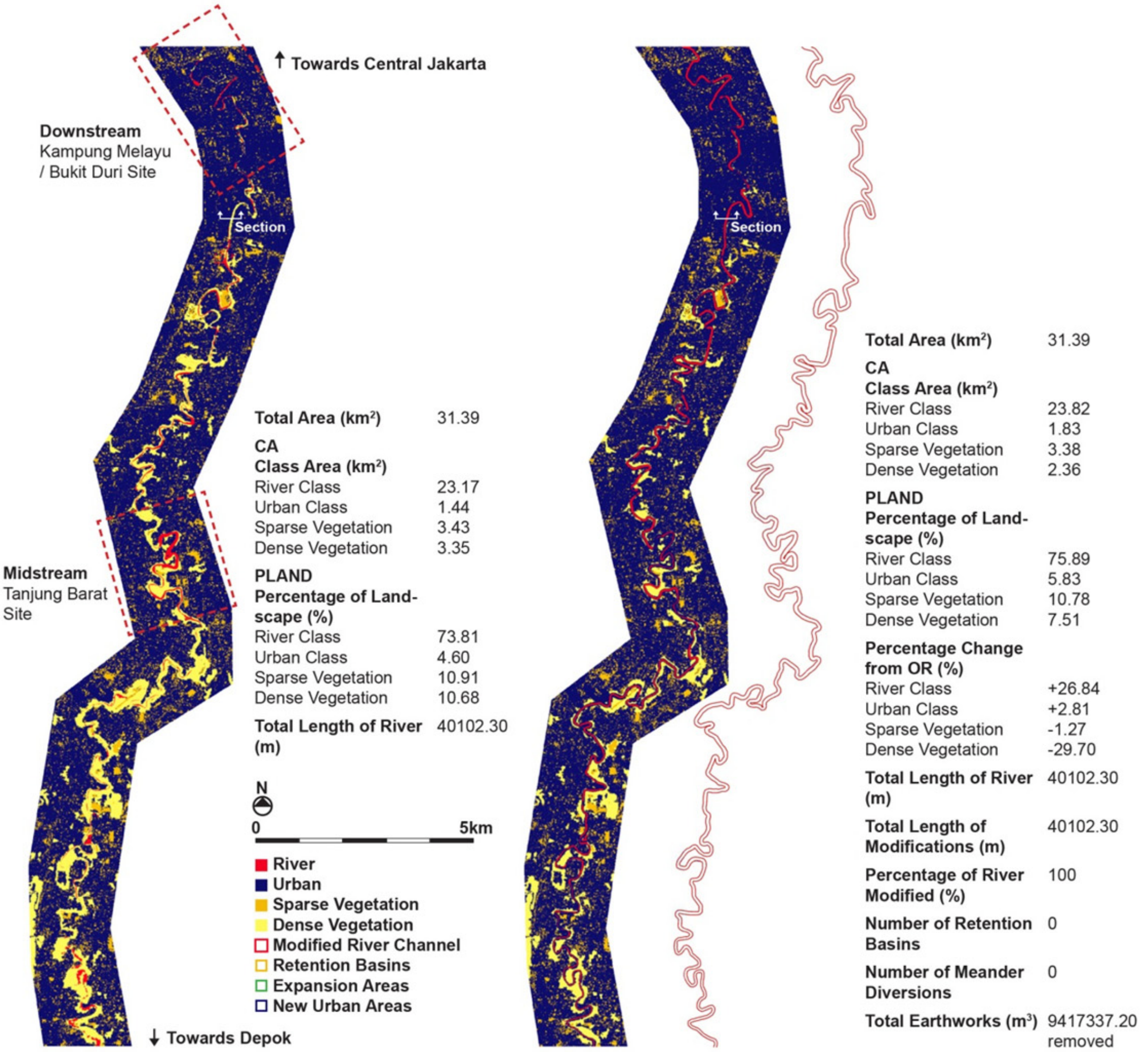
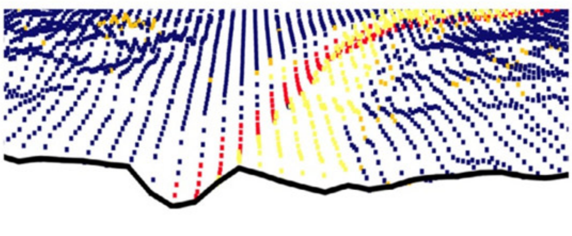


Fig. 4.18: For the Green Infrastructure (GI) Scenario, potential areas along the river were designated as retention basins and expansion areas whereby the river could overflow to safely in times of flooding. Here the results from the simulation show the filling up of the designated areas is seen in both instances during a high flow event.

These three scenarios FN, PN, GI along with the original scenario OR were similarly quantified along with addition information such as the number of retention basins, the amount of earthworks required as well as with basic metrics to help understand the differences between them (Fig 4.19). All the scenarios were then subjected to the hydraulic simulations of which the results from this will be discussed next.

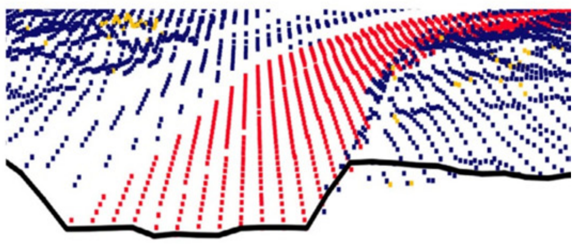


Original Scenario (OR)



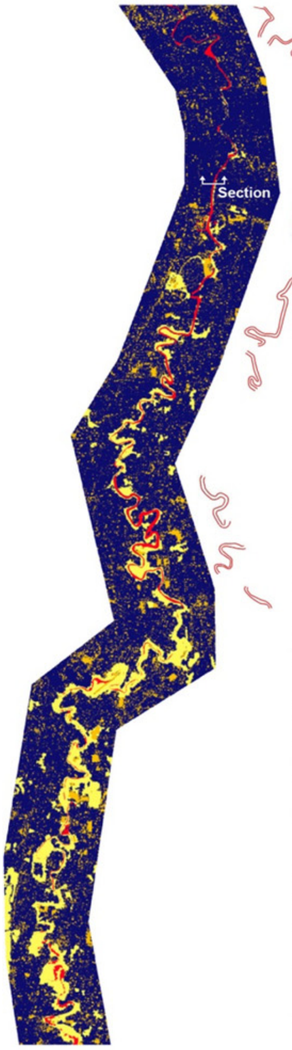
The original scenario serves as a baseline to which the other 3 infrastructural change scenarios will be compared against. In general, the river is relatively narrow throughout its course and urban sprawl encroaches onto its banks along the downstream half of the study area, Along the upstream half of the study area the banks are typically lined with vegetation with pockets being cleared for urban redevelopment.

Full Normalization Scenario (FN)

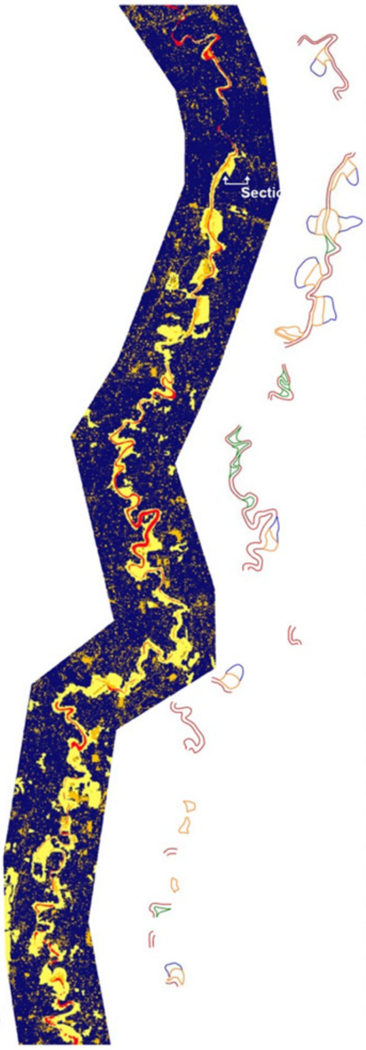


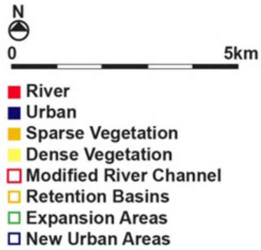
The full normalization scenario is one which carves out a traditional trapezoidal section across the entire course of the river. Based on the normalization plans, this often is done with the use of concrete piles to stabilize the banks together with extensive dredging of the river to a predetermined depth which is calculated to allow for a particular discharge rating. The banks are lined with service roads which serve as dykes. In this scenario no additional provision for riparian vegetation was provided for.

Fig. 4.19: Details of the 3 infrastructural change scenarios which include topographical and land use changes along the riparian corridor.



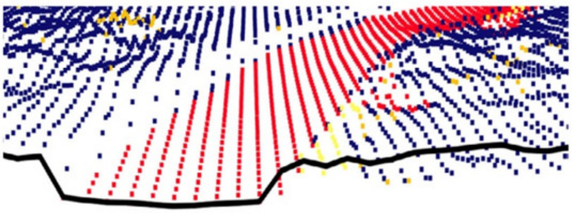
Total Area (km²)	31.39
CA Class Area (km²)	
River Class	23.25
Urban Class	1.56
Sparse Vegetation	3.43
Dense Vegetation	3.16
PLAND Percentage of Land-scape (%)	
River Class	74.06
Urban Class	4.98
Sparse Vegetation	10.91
Dense Vegetation	10.06
Percentage Change from OR (%)	
River Class	+8.20
Urban Class	+0.33
Sparse Vegetation	-0.03
Dense Vegetation	-5.81
Total Length of River (m)	40102.30
Total Length of Modifications (m)	14942.81
Percentage of River Modified (%)	37.26
Number of Retention Basins	0
Number of Meander Diversions	3
Total Earthworks (m³)	452378.88 required





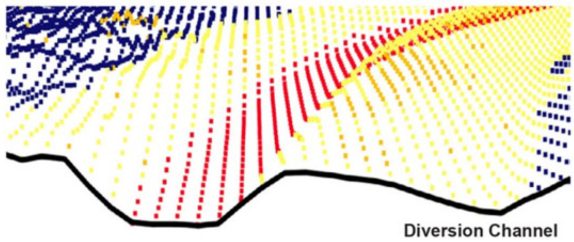
Total Area (km²)	31.39
CA Class Area (km²)	
River Class	22.84
Urban Class	1.26
Sparse Vegetation	3.50
Dense Vegetation	3.80
PLAND Percentage of Land-scape (%)	
River Class	72.74
Urban Class	4.01
Sparse Vegetation	11.15
Dense Vegetation	12.09
Percentage Change from OR (%)	
River Class	-12.74
Urban Class	-1.45
Sparse Vegetation	+2.19
Dense Vegetation	+13.27
Total Length of River (m)	40102.30
Total Length of Modifications (m)	23600.69
Percentage of River Modified (%)	58.85
Number of Retention Basins	13
Number of Meander Diversions	7
Total Earthworks (m³)	8870.880 removed

Partial Normalization Scenario (PN)



Seen as the most likely short term solution currently being implemented, here the normalization only takes place across 37% of the river corridor. and only along the downstream half of the study area. In comparison with the full normalization scenario, the river is not dredged as extensively. In this scenario there are 3 meanders which have been diverted with the resulting land freed up for urban redevelopment. Again, no additional provision for riparian vegetation is provided for in this scenario.

Green Infrastructure Scenario (GI)



The green infrastructure scenario comprises of several strategies aiming to control the flood through a series of ecologically centred modifications. The first being the provision of 13 retention basins along the course of the river, these were built along areas which are frequently hit by floods as well as 7 selected meanders which were diverted to form the retention basins and areas for new urban redevelopments. In addition, expansion areas allow the river to expand during high waters.

4.3.5 Hydrodynamic Simulation Results and Discussion

It has already been shown that the results of hydrodynamic simulations could allow for the comparision of alternative future scenarios at the site scale (Chapter 4.2.2). At the corridor scale discussed here, the same method allows us to compare the different responses the 6 scenarios produce. Figure 4.20 compares the outflow hydrograph for the different land use scenarios when modelling same inflow 2 year Nakayasu Synthetic Unit Hydrograph (in blue) as the inflow. Here, the land use scenarios OR_U and OR_V do not significantly alter the passage of the flood wave, this despite having a 66.3% decrease in the area of the dense vegetation classification for OR_U and a 29.1% increase for OR_V compared to OR. While land use changes in the broader catchment can, at the small scale, significantly affect runoff times, in an already heavily urbanised river corridor - with more than 70% urban coverage - the net effect of such changes appears to have a negligible effect on the hydrograph.

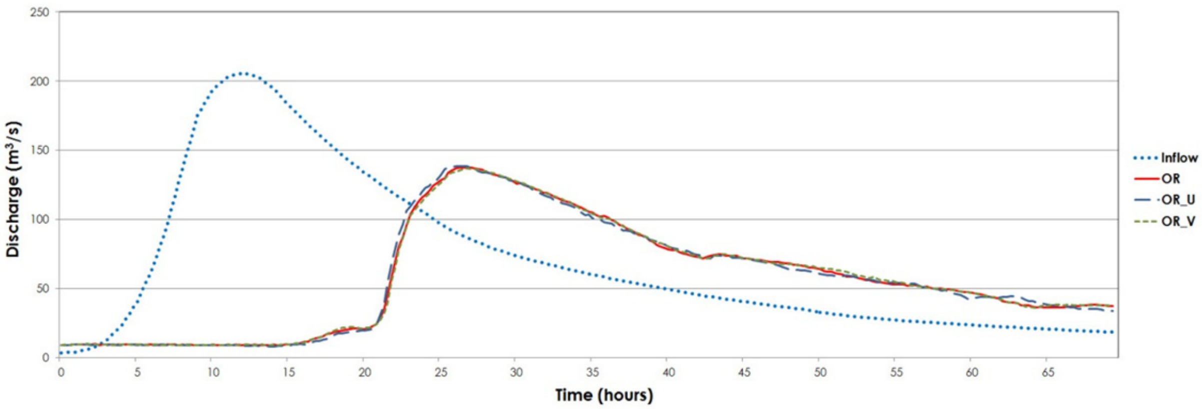


Fig. 4.20: The hydrograph comparing the discharge for the OR, OR_U and OR_V scenarios reveals an insignificant change in the discharge curves across all three scenarios

Further, Figure 4.21 summarises the calculated bed shear stress for each cell during the entire span of 185 hours simulation and plots the results on a semi-log scale. The bed shear helps predict the 'moving' power of the river in the form of erosion and deposition. The impact of 'smoothening' of the terrain due to land use changes become more clear especially in the higher range of the bed shear stress, yet with the overall change does not appear to be significant. From these results, it would seem that changes in the amount of riparian vegetation produce an insignificant change to the simulated flood. However, as it is known that vegetation has a complex but direct influence on bank stability (Merritt 2013; Corenblit et al. 2014), it would be premature to dismiss the role of riparian vegetation in river management based on these results alone and it is likely that a more complex numerical model is required to fully simulate these effects.

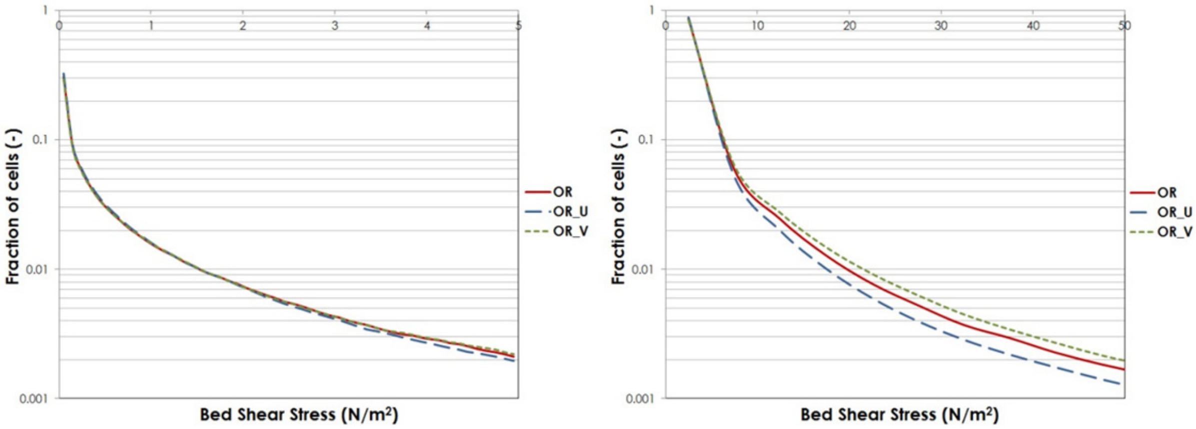


Fig. 4.21: Comparing trends in calculated bed shear stress for all cells over 185 hours of simulation for the OR, OR_U and OR_V scenarios reveals rather insignificant changes in the bed shear stress between the scenarios.

In comparison, infrastructural interventions such as those created in scenarios FN, PN and GI produced more significant differences as observed via the results. The change in the nature of the attenuation and diffusion of the flood wave can be seen in the hydrographs of scenarios FN, PN and GI (Fig. 4.22). According to the results, the peak flow only increases marginally; however, the rising limb of the hydrograph starts to upsurge up to 5 hours before the time simulated for the OR. This is consistent with the greater conveyance expected with the various degrees of channel widening for all 3 scenarios.

While during OR, the terrain is able to - or perhaps forced to - store some of the extra water on the flood plain during the flood event and gradually release it after the flood event, the FN and PN scenarios show a drop in capacity to do this – as can be seen by the falling limb of the hydrographs that quickly fall below the OR scenario. Overall, the size and volume of the flood wave carried to the outflow in the FN and PN scenarios increases due to the infrastructure interventions, thus placing an increased strain on the channel system downstream of the outflow (Mangarrai Barrage & Downtown Jakarta), which already struggles to remove the excess water to the Java sea during high tide and flooding season. The GI scenario on the other hand, is quiet similar in to response on the falling limb section as the OR case.

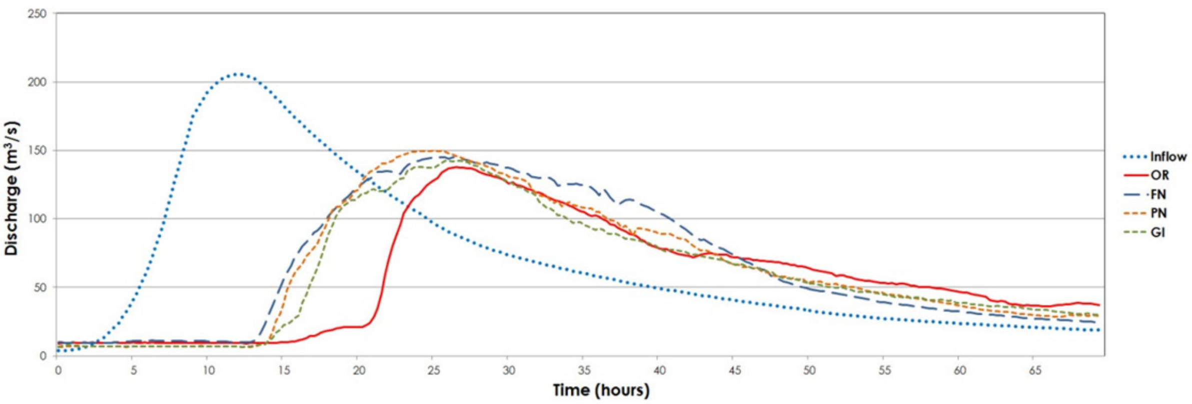


Fig. 4.22: The hydrograph comparing the discharge for the OR, FN, PN and GI scenarios shows a clear differentiation between the scenarios in which the FN and PN scenarios in particular are seen to be more reactive, increasing the size and volume of the flood wave

Looking at the inundation extents projected by the simulations, Figure 4.23 summarises the net 185 hour run for the three infrastructural change scenarios (FN, PN, GI) against the original scenario (OR). The maps plot the net probability of a cell being wet during the entire simulation. Since the simulation consist of a 'low frequency, high volume' flood and 'high frequency, low volume' flood, the map characterises the high and low risk areas for flooding. Compared to the base case, OR, it can be seen that all the other scenarios, perform at least marginally better – with FN performing as expected by containing almost all the water into the modified channel without much overflow. The retention basins and expansion areas of the GI scenario similarly perform as expected during the floods, however the net inundated area does not seem to drop significantly.

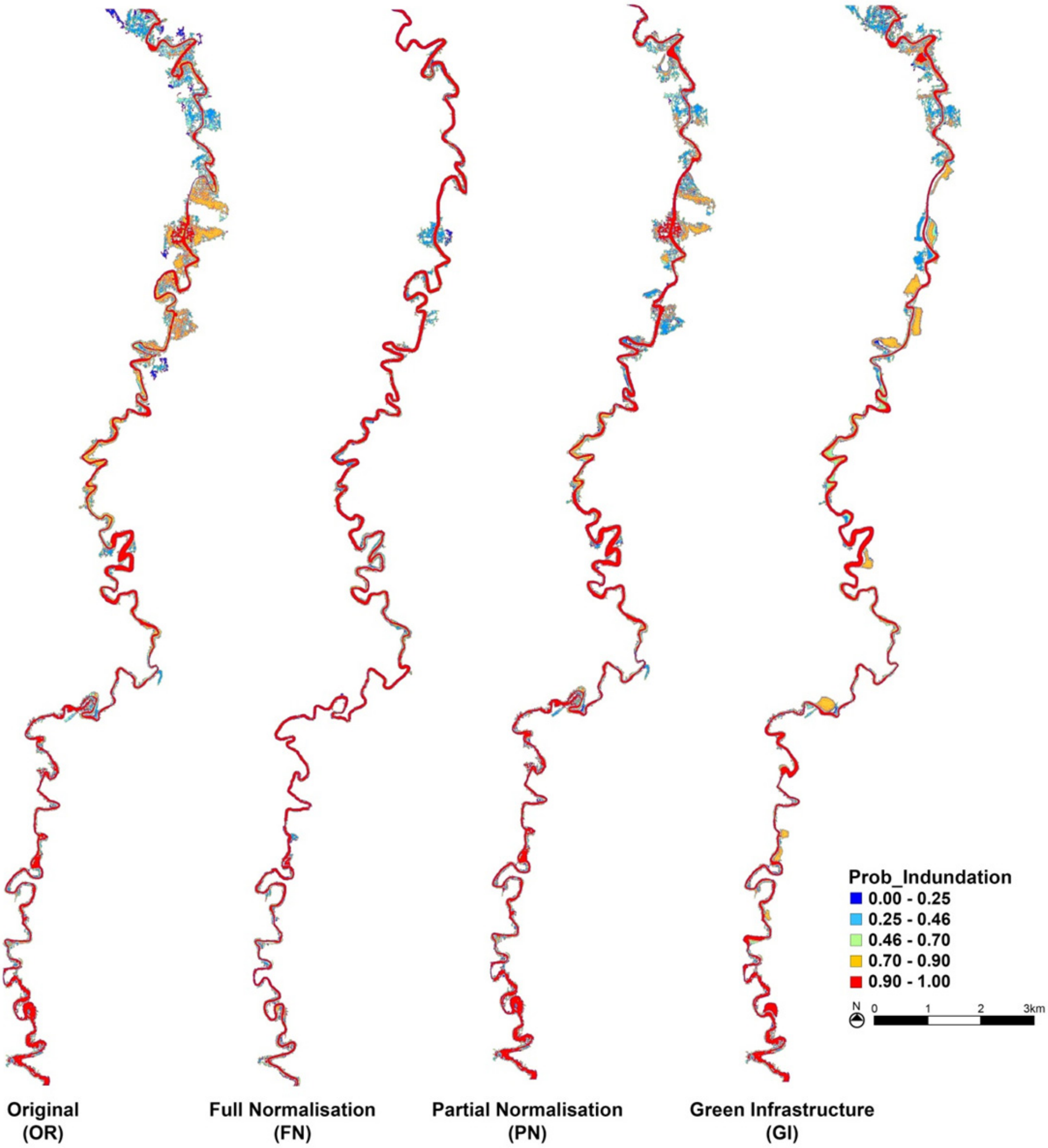


Fig. 4.23: Probability of any cell in the modelled domain to be inundated over the total 185 hours of simulation for the OR, FN, PN and GI scenarios. Here based on visual inspection alone, it would seem that the FN scenario is most successful in containing the flood waters.

Taking into consideration the inundation extents alone, it seems that the full normalisation scenario would be the best option for flood mitigation on the account of it being able to contain almost all the flood waters, however, besides the increased strain on the downstream infrastructure as previously highlighted, the bed shear stress plots (Fig. 4.24) clearly indicate a significant rise in the 'moving' power of the stream for the FN scenario, over the 1-5 N/m^2 range (moving range for fine to coarse sand/silt or clay particles). It stays above the other scenarios till ~ 30 N/m^2 before conforming to the general trend. Considering how most of the FN channel comprises of bank stabilisation works which leave the river bed untouched, this would likely cause serious erosion problems in the long run. As it is, the Ciliwung transports a lot of fine sediment and with sedimentation comes the constant need to dredge the river to retain its conveyance capacity. It is already a constant challenge to maintain existing flood control infrastructures (Fig. 4.25), any further strain on the already heavily taxed system and might result in a cycle of "chasing the river" (Schiff et al. 2007), requiring more and more bank reinforcements further downstream.

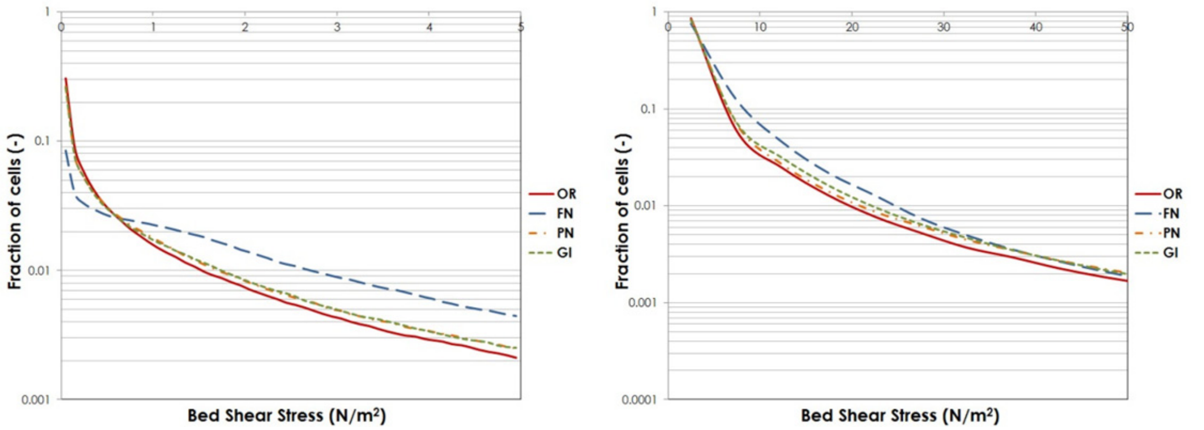


Fig. 4.24: Comparing trends in calculated bed shear stress for all cells over 185 hours of simulation for the OR, FN, PN and GI scenarios show that the FN scenario has a higher tendency to cause erosion.

Fig. 4.25: The Mangarrai Barrage, just downstream of our corridor scale outflow, requires routine dredging of sedimentation and trash in order to function adequately as a flood control infrastructure.

In addition, the calculated earth works required for the FN scenario run up to over 9 million cubic meters of earth which need to be excavated in order to achieve the width and depth required to hold the flood wave within the constraints of the channel. This is a far cry compared to the 8 thousand cubic meters for the GI scenario. That said, the GI scenario similarly requires extensive work at multiple locations along the entire course of the river as no single GI intervention can effectively mitigate the effects of flooding (Liu et al. 2014). The implementation of any extensive GI project will also likely be faced with difficulties as floods might destroy them even before the vegetation has a chance to establish itself (Ayuningtyas 2013). It would however be helpful to further investigate the possibility of reinforcing the banks with fascines made from green wood of local riparian species which might be able to establish themselves before this happens.

As mentioned, the PN scenario represents the most likely intervention currently being carried out on the Ciliwung River due to its less extensive and invasive nature. Based on the results of the simulation it does appear to slightly alleviate the flooding issue but it is likely that this still requires other flood mitigation strategies outside the boundaries of our study area. Currently this includes the building of dams upstream - although this has been fraught with difficulties and delays since its inception in 2004 (The Jakarta Post 2004; Natahadibrata 2015) – as well as a multi-billion dollar sea wall project which is similarly facing controversy (Pelupessy 2014; Dewi 2014).

4.3.6 Landscape Metrics Results and Discussion

When cross referenced against one another, the landscape metrics results from the dense vegetation class correlate with our understanding of the changes made across the scenarios. The most obvious difference being the OR_U scenario which saw a removal of more than 200ha of dense vegetation which is reflected in the resultant metrics; here we see that the OR_U scenario has the smallest average patch size with the highest degree of segregation. A similar trend between the loss of vegetation and increased segregation is seen across the FN, PN and GI classes although the difference between these classes is not as pronounced (Fig. 4.26).

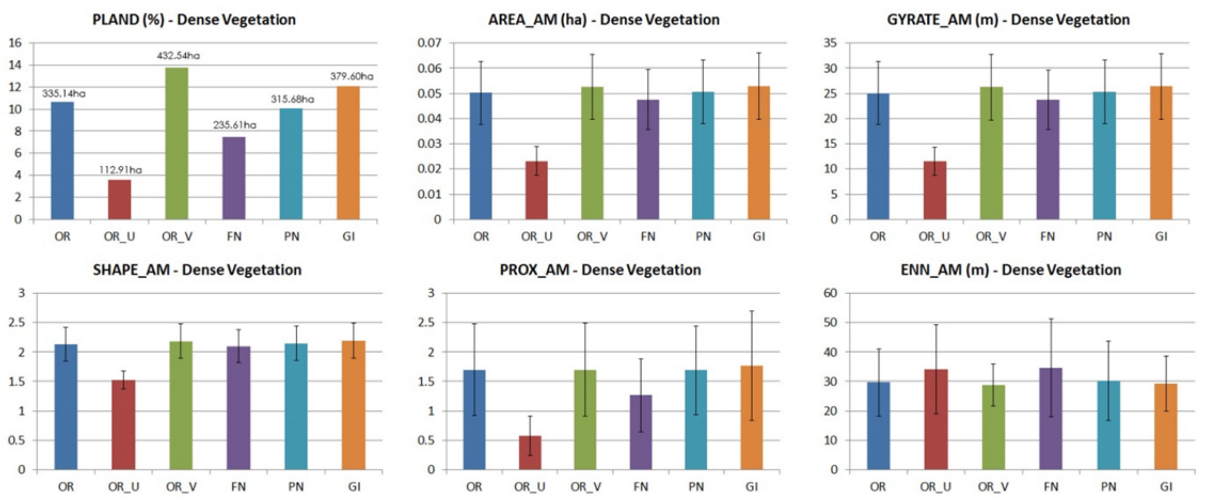


Fig. 4.26: A series of 6 landscape metrics results of the dense vegetation class for the 6 corridor scale scenario changes. These metrics include Percentage of Landscape (PLAND) as well as area weighted Mean Patch Size (AREA_AM), Radius of Gyration (GYRATE_AM), S

The original intention for calculating landscape metrics at the corridor scale was to see if there was a correlation between the changes in the degree of vegetation and the results of the flood simulation. Unfortunately, while the metrics for the dense vegetation class indicates the expected changes across these scenarios, they are inconsequential when attempting to use them in reference to the flood simulation results as the flood simulations seem to be insensitive to the changes in riparian vegetation - based on the results gathered from the OR, OR_U and OR_V scenarios. This might be due to a number of factors, the first being that the models used to run the hydraulic simulations do not fully capture the effects of riparian vegetation (considering the only value used to indicate changes vegetative cover is the associated friction value), or it could also mean that the vegetation itself is not enough to make a significant impact on the flood wave - both of which cannot be verified without empirical testing.

In comparison, the flood simulation results presented are much more sensitive to geomorphological changes to the river corridor as seen in the results from the FN, PN and GI scenarios. Perhaps this is a possible reason why there has been an identified lack of studies which attempt to link landscape metrics to regulation functions and values of ecosystems and landscapes. In addition, while the numbers were tallied (Table 3.9), the thesis found it difficult to firstly comprehend what the numbers truly meant from a design or planning point of view, and secondly to see any means in which they would influence iterations in the proposed scenarios. As such while it is a definite possibility to run such analysis, perhaps in this case it was not the most useful method of quantifiable analysis. Further discussions and recommendations on this matter will be discussed in the final chapter.

Table 4.3: Landscape Metrics Evaluating the Dense Vegetation Class of the Different Scenarios. Class Area (CA), Percentage of Landscape (PLAND), Patch Number (NP), Patch Density (PD), Mean Patch Size (AREA_AM), Area Weighted Mean Patch Size (AREA_AM), Mean Radius of Gyration (GYRATE_MN), Area weighted Radius of Gyration (GYRATE_AM).

	CA (ha)	**PLAND (%)**	**NP (No.)**	**PD (No./100ha)**	**AREA_MN (m^2)**	**AREA_AM (m^2)**	**GYRATE_MN (m)**	**GYRATE_AM (m)**
OR	335.14	10.68	12263	390.62	0.027	0.050	13.65	25.06
OR_U	112.91	3.60	11252	358.42	0.010	0.023	5.35	11.54
OR_V	432.54	13.78	14397	458.60	0.030	0.053	14.99	26.26
FN	235.61	7.50	8943	284.87	0.026	0.048	13.18	23.75
PN	315.68	10.06	11417	363.68	0.028	0.051	13.83	25.30
GI	379.60	12.09	13101	417.31	0.029	0.052	14.49	26.40

4.4 Real World Application Attempt

4.4.1 The Plight of Kampung Pulo

All of the DRS work has been concentrated on the downstream Kampung Melayu/Bukit Duri site of which the village of Kampung Pulo is reputed to not only be the area worse hit by the floods (Fig 4.27) but also conjures up the most political sensitivity. Elections were held in September 2012 for the post of Jakarta City Governor which saw two political outsiders being elected, Joko Widodo as the Governor (now the President of Indonesia) and his running mate, Basuki Tjahaja as his Vice-Governor. Perhaps understanding the gravity of the issue plaguing the Ciliwung River and its residents, the two not only held press conferences standing on bamboo rafts in the middle of the Ciliwung River but even went on to stage their gubernatorial inauguration in a kampung in East Jakarta rather than in the Jakarta City Hall (The Jakarta Post 2012; Cairns et al. 2013) thereby proclaiming their desire to clean up the Ciliwung River and to bring respite to the recurring floods.

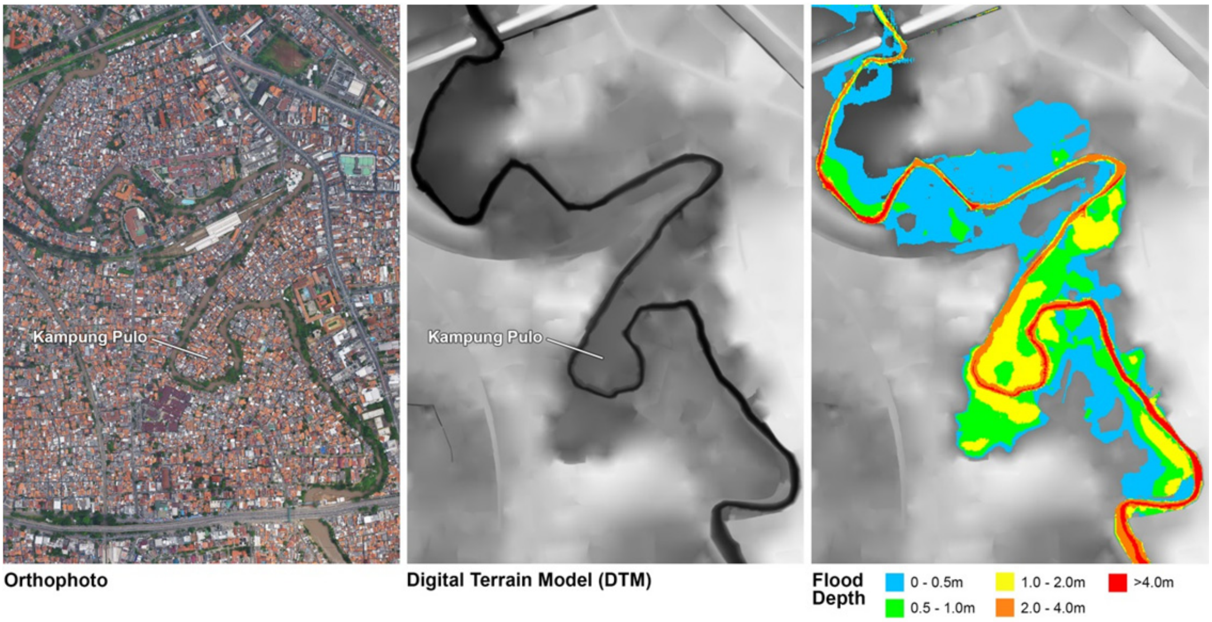


Fig. 4.27: Based on the flood simulations as well as informal interviews with locals, the village of Kampung Pulo is often one of the worst hit during a severe flood.

Within the first hundred days of being elected Governor, a major flood in January 2013 put the new governer to the test (Vaswani 2013a) after which major floods continued to hit Jakarta repeatedly in the years to come with residents reporting of a marked increase in the frequency of the floods (Vaswani 2013b; Setiawati and Dewi 2013; Wardhani and Elyda 2014; Pratiwi 2015). This has resulted in immense pressure for the government to accelerate the normalisation plans for the river which would result in evictions of residents residing in and around Kampung Pulo. While evections are never ideal, it was reported that the increasing severity of the floods have made residents who were previously against the idea accept that relocations have become inevitable (The Jakarta Post 2011, 2015a).

With the real possibility of evictions looming, the team was contacted towards the end of the project to assist in the running of flood simulations. Alternative social-housing proposals were being prepared by Ciliwung Merdeka, a non-governmental organization (NGO), as a counter proposal to the government's plans for relocation. To substantiate their proposal, they were hoping to hinge off our findings with respect to the floods to help support their case. This section details the attempt of preparing these scenarios and running the flood simulations to be as reliable as possible within the constraints given.

4.4.2 Traversing Between Scales

While the area of interest described here is once again reduced to the site scale, the thesis attempts to traverse across the scales by using results from simulations performed by different members of the team (Fig 4.28). It firstly uses results from hydrologic simulations the catchment scale to provide the hydrograph to run simulations at the corridor scale. The corridor scale simulation then provides yet another hydrograph for the site scale which represents a moderate and fairly recurrent event for the river system - a flood with a 2 year return period with the assumption that no changes were made to the upstream regions. The simulation results at the site scale are expected to allow members at the Ciliwung Merdeka to understand the possible risk areas and be able to design around them. This rather tedious method of traversing simulation results between scales was done in anticipation that possible changes at the catchment or corridor scales can also be taken into account if the need to do so arises (Remondi et al. 2016; Lin et al. 2016).

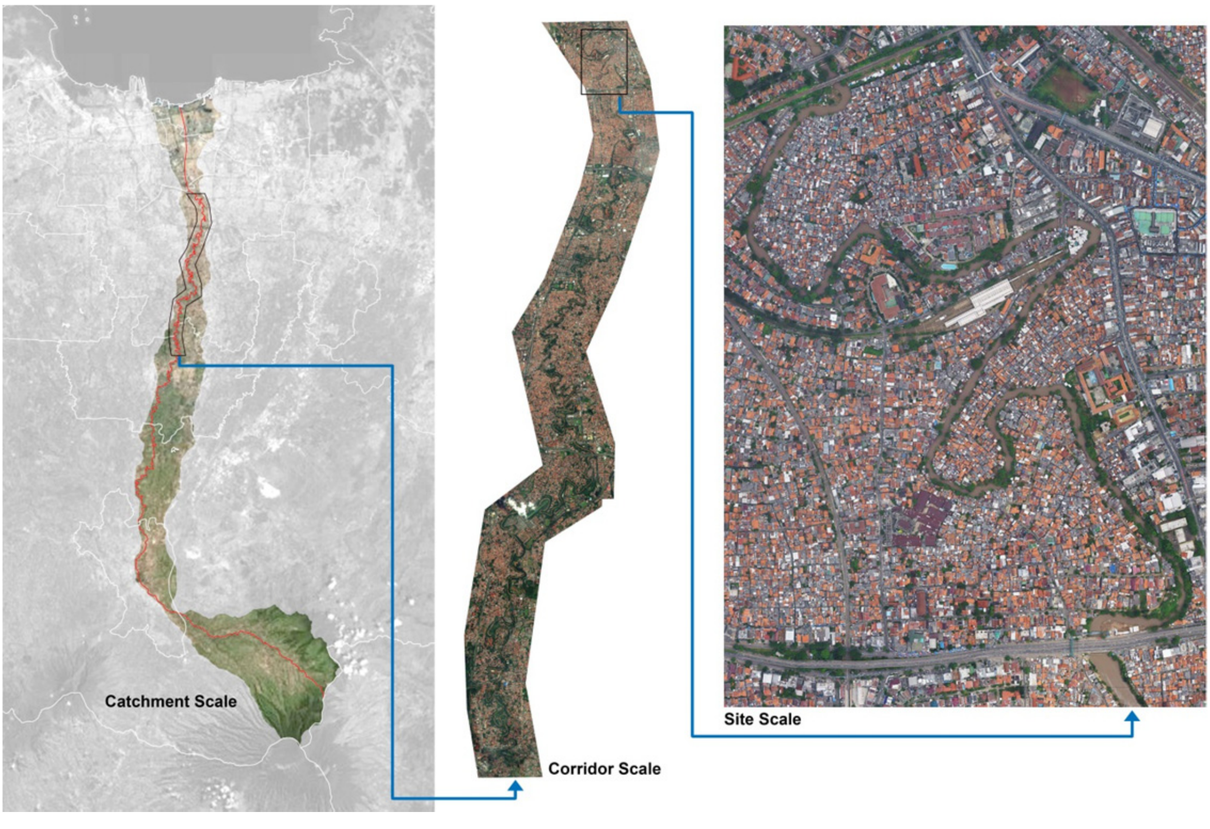


Fig. 4.28: Simulation results were extracted at the boundary of each of the preceding scales in order to produce a hydrograph which would then be used at these scales. The reason for doing so is to provide the opportunity to see if changes at the catchment and corridor scale might affect the site scale flood simulation results.

4.4.3 Establishing a Baseline

Establishing a baseline is an essential requirement in measuring the eventual performance of any given scenario. In terms of flood mitigation performance, we first need to establish a reliable flood outline. Prior to the availability of hydraulics simulations the DRS students relied both on available flood extent maps as well as abstractions based on interviews with residents (Chapter 4.2.1). These maps proved useful only to have a very basic understanding of the extent of the flood but lacked other critical information, such as the depth and velocity of the water, both critical in determining the potential damage or hazard the floods pose as well as providing crucial information to begin designing flood mitigation strategies. Subsequently, a simulated baseline flood was used in order to compare the results across different designed scenarios (Chapter 4.2.2). However at that junction in time, we had neither a properly prepared digital terrain model nor the hydrograph based on historical collected data. This was not an issue as those experiments were purely academic in nature and was meant to demonstrate a method as opposed to testing real life plausible scenario. In comparison, to apply the same tools and methods in a possible real world scenario, the team needs to ensure that the flood simulation be as representative as possible given the constraints of technicalities, data and time.

The most problematic issue was selecting the appropriate terrain model to run the flood simulations over as the flood results could vary widely depending which model was chosen or how the data was prepared (Shaad et al. 2016). While all terrain models are artificial constructs of reality, selecting or modifying one which would best represent the true nature of the flood was the first task to be tackled. The first simulations were run using a DSM with a theoretical river bathymetry carved into it leaving all buildings and vegetation intact. As the flood simulation at the moment does not allow for "permeable" objects, all vegetation canopies and buildings were treated as entirely solid objects. Considering how the tree canopies often obscure the view of the river and how dense the urban settlement is, this creates a situation whereby the river and the flood is artificially constrained.

The thesis thus went about to test three different modified terrain models all of which were classified and appended with the appropriate friction values; a Hybrid DTM in which vegetation and areas classified as open space are flattened but the urban settlement remains untouched; a Bare Earth DTM in which all buildings and vegetation were flattened and only the ground is used; and lastly an Raised DTM in which the areas of the Bare Earth DTM is raised artificially based on the underlying urban classification. This Raised DTM was created by starting with the Bare Earth DTM but artificially raising the areas classified as urban settlements by a predefined height based on their original classifications (Table 4.4), this was done in anticipation that it would better represent the buildings as an obstacle to the incoming flood but still have them remain susceptible to flooding when the flood waters exceed a certain threshold. The heights selected in this case were a result of discussions with the engineers with the assumption that a taller building would typically be more resilient to flood waters.

Table 4.4: Urban classification type and height raised above ground level to form the Raised DTM

Classification	Height Raised (m)
Urban <5m	0.5
Urban 5-10m	1.0
Urban 10-15m	2.0
Urban >15m	4.0

After running the simulations through the different DTMs, the results were used to produce three different maps (Fig 4.29). A flood depth map which helps to identify areas which would be of concern should settlements be flooded; a bed shear stress map which helps identify areas in which erosion and deposition might occur (based on discussions with engineers in the team & data from Berenbrock and Tranmer 2008); and lastly a hazard to people map which is a combination of depth and velocity which identifies areas in which pose a risk to humans (Wade et al. 2005). From a comparison between these maps, it was apparent that the Hybrid DTM and Bare Earth DTM resulted in inundations which either masked the severity of the inundation or exaggerated it. In contrast, the Raised DTM appeared to be the most visually representative of our understanding of the flooding extent. While there was no way to calibrate the simulation results with an actual real world flood, they were deemed suitable enough as a guide for Ciliwung Merdeka to begin planning their alternative proposals.

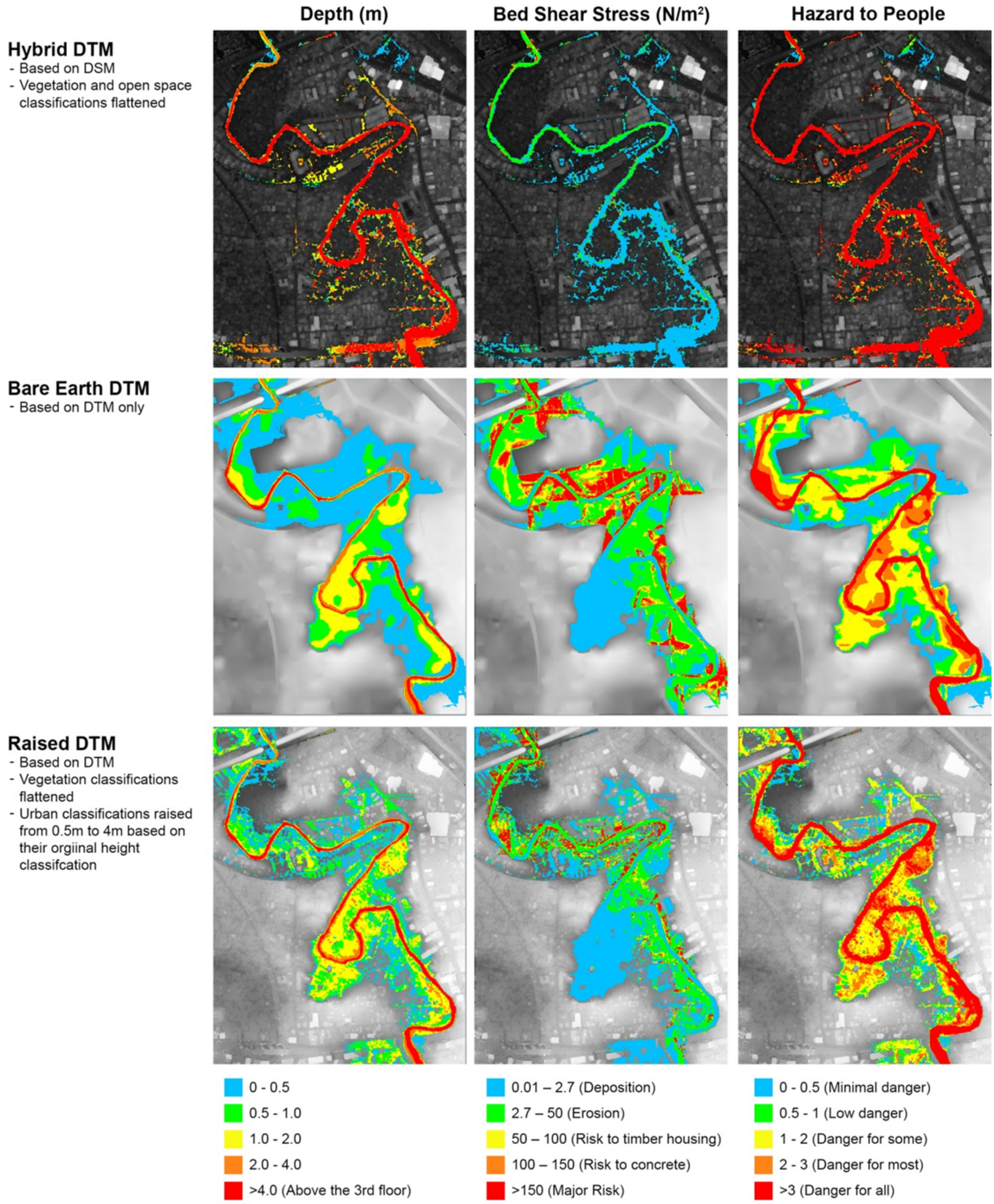


Fig. 4.29: The three different DTMs and flood simulation results indicating the depth, bed shear stress and hazard to people.

4.4.4 Too Little Too Late

Unfortunately despite our efforts in trying to establish a representative baseline for further exploration, our efforts were brought to an abrupt end. For years, the residents in Kampung Pulo have been residing in limbo, teetering between being at risk of inundation or perhaps even worse, forced eviction. While threats of evictions have been ever looming (The Jakarta Post 2011) and multiple appeals have delayed the inevitable (Wardhani 2015), on the 20th of August 2015 forced evictions turned violent (The Jakarta Post 2015b) - much to the dismay of the thesis and academics alike who were working with the residents to find less a obtrusive method of relocation (Voorst and Padawangi 2015). While opinions have been divided on this matter with some siding the tough stance employed by the new Jakarta Governor Basuki “Ahok” Tjahaja Purnam, believing that doing so will bring about a “flood free” Kampung Pulo (The Jakarta Post 2015c), others have been quick to criticize the move (Kompas Cyber Media 2015; Coconuts Jakarta 2015).

These evictions have paved the way for the FN or PN scenarios to be implemented in a most literal translation whereby any structures, natural or manmade, falling within the defined boundaries were completely flattened and the banks of the river altered to make way for the concrete piles and service roads (Fig 4.30). These drastic changes to the river channel mean that all the baseline results previously established were not only made invalid but also that there was neither the time nor resources to reestablish a new baseline to carry on working with Ciliwung Merdeka. As such, while evicted residents continue to fight for their rights hoping to have their voices heard (Mariani and Wardhani 2015; The Jakarta Post 2015d), the group and thesis has to take a step back to round up its findings.

Fig. 4.30: Photos taken in October 2015 showing the process of normalisation happening to the residents of Kampung Pulo whereby settlement and vegetation alike are removed to give way to a concretized river edge.

While the ongoing situation in Jakarta is certainly disheartening, the data, tools, workflows and scenarios developed and tested throughout the course of the thesis has indeed shed light on the issue of using point clouds as a representative and performative format for landscape architecture. These findings will be discussed in the following concluding chapter.

Chapter 5 – Discussion and Conclusion

5.1 Overview

The thesis set out to explore the potential of point clouds serving simultaneously as both a representative and performative format for landscape architectural projects. In doing so, it seeked to provide an insight into the potential influence adopting a point cloud workflow would have to the discipline as well as its application possibilities within the realities found in Jakarta. While it has been demonstrated that the representative and performative function is indeed a possibility, it will be discussed that as a representative format, the current workflow demonstrated in the thesis is greatly hindered by the lack of more sophisticated tools developed specifically to allow landscape architectural elements to be represented as point clouds. As a performative format however, it is anticipated that point clouds have a great potential to provide a deeper understanding of the underlying dynamics of an existing landscape and the potential impacts of different designed scenarios. This is provided steps are taken to align issues of technicality and pedagogy by developing a robust point cloud centric hardware and software environment that is fluid enough such that landscape architects are able to start adopting into their already established workflows.

The final chapter thus breaks the discussion down into several sections, the first two – chapters 5.2 & 5.3 – discuss representation and performance testing separately, highlighting the pitfalls and potentials of each with respect to landscape architecture. Chapter 5.4 outlines the identified challenges ahead ranging from technical to legal complications when attempting to use the technology highlighted in the thesis. Chapter 5.5 examines the findings with respect to point clouds and their potential overarching influence on landscape architecture, and finally chapter 5.6 rounds up the discussion with respect to the case study itself.

5.2 Point Clouds as a Representative Format for Landscape Architecture

5.2.1 Point Clouds versus Other Digital Representative Formats

To understand point clouds place as a representative format, the thesis refers back to Amoroso's 6 main digital representational "drawing types"; Diagrams and Mapping Drawings; Presentation Plans; Section-Elevations; Axonometric Drawings; Perspectives; and finally Digital Modeling and Fabrication (Amoroso 2014b). Of these 6, presentation plans are still seen as a cornerstone of landscape representation often consisting of two dimensional line drawings as a base over which additional layers of information, textures and colours are added to produce the final representation, this two dimensional abstraction however not only makes them less effective at communicating spatial information to non-designers than other representative formats (Zeunert 2014) but is also currently impossible to derive automatically from three dimensional point cloud models alone. Similarly, while it is possible to produce diagrams and maps (such as flood hazard or classification maps shown in chapter 4), these representations are not leveraging on the three dimensional nature of the point cloud. In fact if all that is required is a map or other two dimensional diagram, it would likely be disadvantageous to apply a point cloud workflow simply because there are software packages and well established workflows that are much more adept at dealing with two dimensional modes of representation.

In comparison, other representative formats such as sections and elevations begin to take advantage of point cloud data. Sections and elevations can be easily projected by slicing the model at the appropriate plane; its effectiveness depends largely on the data available and the scale at which the data was collected. At the site scale for example, orthographic sections are difficult to understand due to the lack of resolution but data collected at the local scale can readily produce elevations of scanned buildings and streets (Fig. 5.1). At this scale, sectional perspectives or axonometric projections further extend the potential of point clouds to represent possible designed scenarios and provide a better understanding of their spatial qualities by modifying existing captured scans and injecting designed proposals (Fig. 5.2).

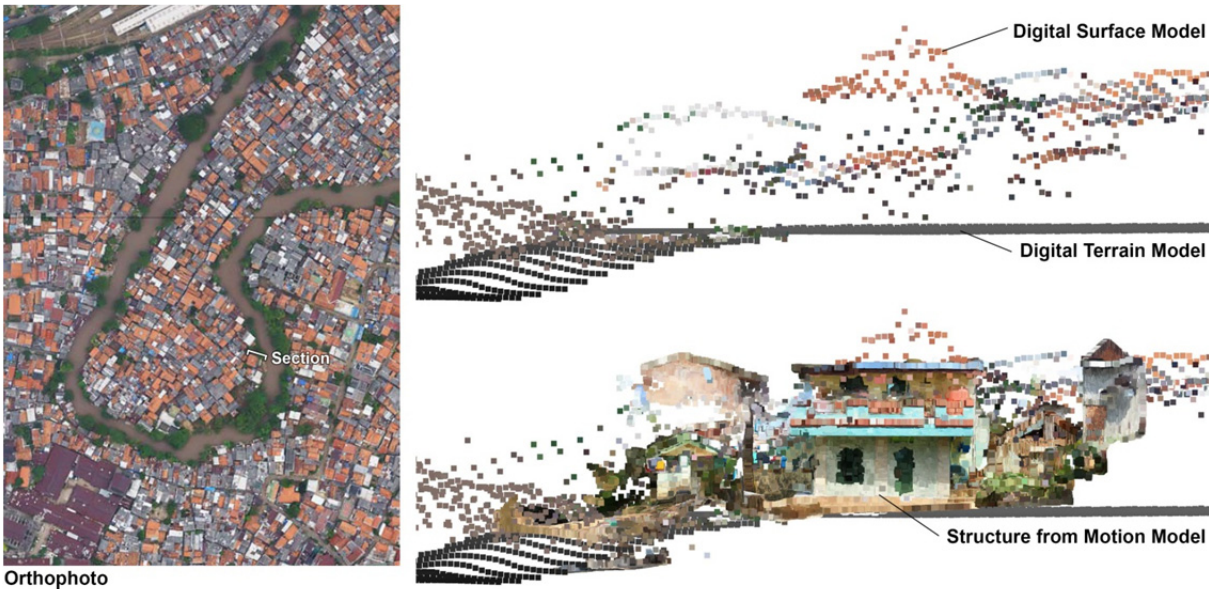


Fig. 5.1: Sections through the DSM and DTM site scale point cloud models are difficult to read due to the lack of resolution at this scale. In comparison, a point cloud model collected at the local scale combined with the DTM and DSM models provides for a more readable section.

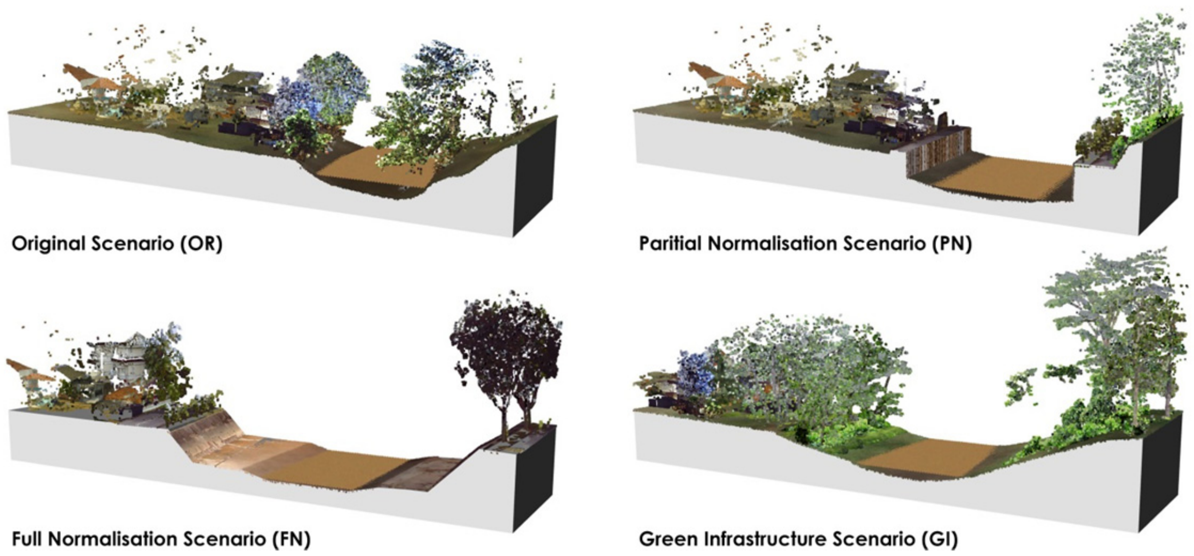


Fig. 5.2: Using ground based data collection methods (Rekittke et al. 2012b) and the tools developed, the three infrastructural change scenarios described in 4.3 were represented as a sectional perspectives consisting of a 25x100m reach of the river to better understand the different spatial qualities between them.

Considering that reality captured point clouds already exist in a three dimensional space which the viewer can repeatedly revisit from multiple angles, they are particularly adept at representing the landscape in the form of both fixed perspectives (Fig 5.3), animations (Fig 5.4) and even real time walkthroughs.

Fig. 5.3: An example of a fixed perspective combining point cloud data obtained from a terrestrial laser scanner, bathymetric section lines acquired during an expedition and a site photo in the background (Ninsalam et al. 2015).

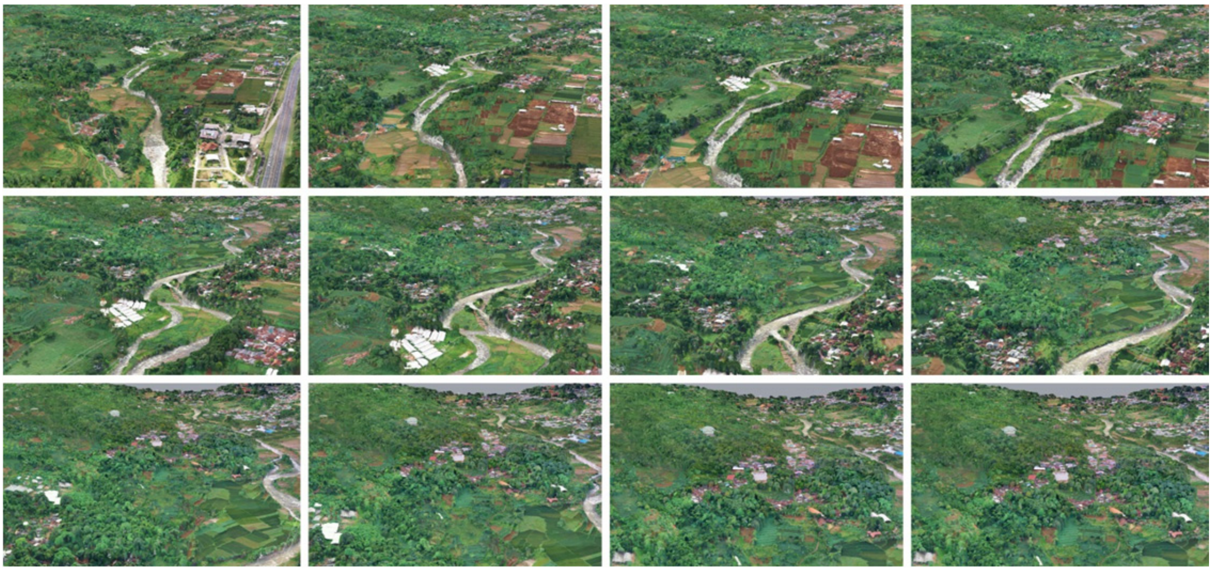


Fig. 5.4: Frames extracted from a minute long animation showing a fly through over the point cloud model collected of the Ciliwung River at the upstream Gadok / Katulampa site.

The techniques and technologies used to acquire reality captured point clouds are constantly improving but representing landscape architecture goes beyond technical surveying methods and is focused on the in the injection of designed landscapes into existing ones. This is where the main problem with using point clouds to represent landscape architecture has been identified. Even with the tools developed, it is still difficult and cumbersome to create realistic looking representations. While they have allowed for the creation of new point clouds to represent design intent, surface models are still needed to be created before having their surfaces populated with points, making it more of a work around rather than a true workflow which “stays in the cloud”.

This coupled with the inability to cast light onto the point cloud model, the need to manually texture each individual point and the lack of any point cloud based libraries of vegetation and objects makes it an excessively tedious process to produce realistic looking representations (Fig. 5.5). If the intention was purely to produce a perspective for visualisation sake, other methods used by the students would have been not only more visually realistic but also more efficient as there are already commercially available tools for representing large areas of vegetation complete with the possibility to simulate light and include textures (Fig. 5.6).

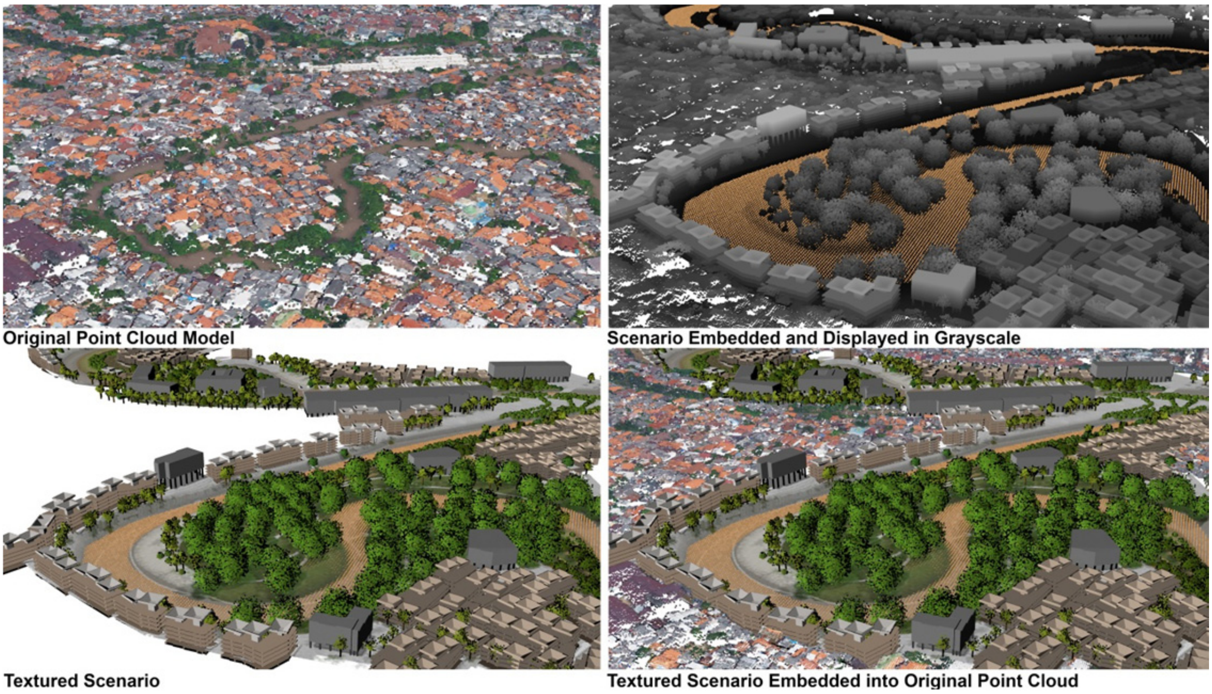


Fig. 5.5: Using one of the students proposed scenarios and fleshing it out in point clouds proved to be a daunting challenge. Creating the scenarios in a point cloud format is not only a tedious process but the difficulties in texturing and lighting it make it very difficult to obtain realistic looking representations of the landscape.

Fig. 5.6: The same scenario and viewing angle was produced both in point clouds as well as one which was produced by the students using a variety of other traditional techniques. These include modelling the surrounding buildings from scratch, using a plant library, rendered with lighting and atmospheric filters and finally composited together (Lorraine Haussmann & Kylie Russnaik, for the Rotterdam Biennale 2014).

It is clear that instead of attempting to challenge the representational formats identified, point clouds should be classified under an entirely different category, Digital Modeling and Fabrication. Considering how they are inherently a digital model to begin with, representations of the landscape using point clouds should be produced in a three dimensional medium instead of the two dimensional ones discussed earlier, and this can be done through the application of digital fabrication (Chapter 5.2.2) or virtual reality (Chapter 5.2.3).

5.2.2 Digital Fabrication using Point Clouds

Digital fabrication and rapid prototyping has in recent years become a very popular topic owing to the lowering of costs and other barriers of entry, allowing a revolution of turning data into tangible real-world objects (Gershenfeld 2012). More than just object creation, digital fabrication could even be seen as a new force in the process of bringing powerful ideas, literacies and expressive tools to education (Blikstein 2014). Unlike the craftsmanship which is required to build traditional physical models, digital fabrication relies on the interface between a digital model and a machine which then constructs it though additive or subtractive. While the reliance on a machine can be viewed with a degree of skepticism (Sennett 2009b), it is also argued that a deeper understanding of the digital fabrication process can in contrast lead to a better engagement in the design process (Mah 2014).

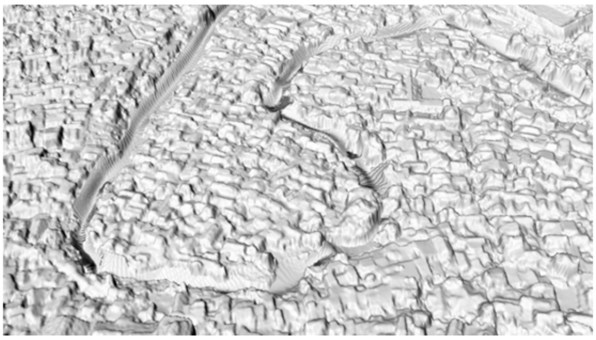
Although often found in product design, architecture, industrial engineering and manufacturing industries, researchers in landscape architecture have also begun to experiment with this emerging technology often by using manufacturing techniques such as CNC milling and laser cutting machines (Gutierrez Gomez 2013). These techniques can be broadly classified into 4 categories; 2D fabrication in which CNC cutting is used to cut forms out of sheets of materials; additive fabrication in which an object is formed by adding layer upon layer of material; formative fabrication in which materials are reshaped using external forces ; and lastly subtractive fabrication in which a specified volume of material is removed from a solid blocks (Kolarevic 2001).

2D fabrication for use in landscape models typically simplifies the landscape into different strata which is fabricated in the form of layers using a laser cutting machine, with each layer of material representing a respective change in topography (Fig. 5.7). While a fair amount of hype of late has revolved around additive manufacturing (Gao et al. 2015) - more commonly referred to as 3D printing - it is an inherently slow process making it unsuitable when attempting to fabricate large models which can represent the vastness of a landscape. Formative fabrication is more often used to create architectural elements such as steam bent wooden boards, deformed metal or molded plastic more suitable for other applications. In comparison to these methods, subtractive manufacturing, often done with a CNC milling machine, is far more suitable when dealing specifically with large topographical representations (Fricker et al. 2012a) as it is capable of fabricating objects which are limited mainly by the size of the machine and the blocks of material. While a fair amount of experience and preparation is required in order to successfully operate a mill, the most important input required from the fabricator is a digital landscape model. This model is then scaled down to the size based on the physical limitations at hand, such as finding a compromise between the desired representative scale or resolution and the size of the milling machine, the milling bits or the blocks of material available.

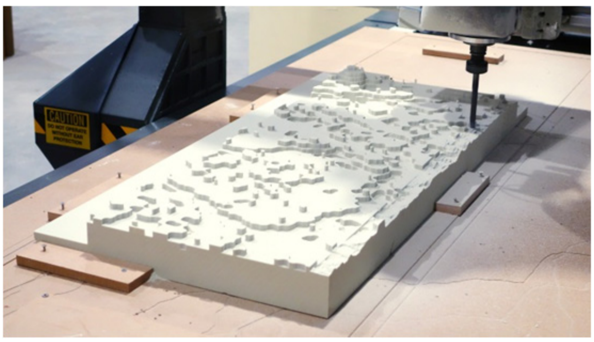
Fig. 5.7: An example of a 2D fabrication method that stratifies the landscape into steps with each step indicating a specific change in topography, created by students of the last DRS with the help of a laser cutting machine (Kowalewski & Hashimoto 2013).

To generate these digital landscape models for use in the milling process, researchers either experiment with generative models in which a series of algorithms create forms out of a range of digital inputs (Mah 2014) or simply build the models from scratch using traditional 3D modelling techniques. An alternative presented here is using the reality captured data collected from the UAV in order to produce a digital model suitable for use in the mill. In this case, the modified point cloud model of the downstream site had to be converted into a mesh model which was then rescaled to fit both the dimensions of the blocks of foam available and the scale of representation desired and finally sent to the mill to be fabricated (Fig. 5.8).

The original point cloud model over the downstream Kampung Melayu site altered to include the river bathymetry within it.



Using the tool PCmesh, the gridded point cloud model is converted into a meshed surface necessary for the milling process.



A 3-axis CNC milling machine was then used to fabricate a physical representation of the digital landscape through subtractive means by the removal of foam by the mill.

A close up view of the finished physical model, the resolution here is determined both by the resolution of the input mesh as well as the smallest milling bit available.

Fig. 5.8: Subtractive manufacturing is an effective process of representing reality captured landscapes. In this case, a modified reality captured point cloud model was as the input necessary to fabricate a physical representation of the landscape out of foam using a 3-axis CNC milling machine.

When comparing the two different approaches, the use of a user built-up 3D model versus a reality captured one as the inputs for the milling process, it would initially seem that the latter lacks the definition of clearly defined outlines of buildings, roads and other infrastructural elements (Fig. 5.9). However, it should be noted that this is a result of the necessary abstractions performed in the manual creation of the digital model as it would be immensely time consuming to accurately model the entire landscape inclusive of all the accurate roof and canopy heights and other nuances which occur in reality. By comparison, the model created from reality captured data presents the data as it was recorded; as such every tree, every roof and all other intricate details in the landscape which can be captured at this scale are represented.

A physical model of the downstream site fabricated from a user generated surface model of the site.

A physical model of the downstream site fabricated from reality captured data from the UAV.

The user generated model provides for clearly defined outlines of buildings, roads and other infrastructural elements. Vegetation is missing in this model as it was not included in the students model.

In comparison, the reality captured model hardly has any well-defined edges but more accurately depicts the density of settlements along the rivers along with all the vegetation captured as well.

Fig. 5.9: While it is common to utilise user generated models to fabricate a physical model, here we see the use of reality captured models to do the same.

Other than being a substantially less biased representation of the landscape, more importantly as the model was fabricated using UAV data, all subsequent layers of generated materials which are geo-referenced to this original data can be perfectly aligned and overlaid over the physical model using a digital projector. This includes the orthophotograph, shaded topographical maps, flood simulation animations, proposed scenarios, survey results and any other suitably geo-referenced layers (Fig. 5.10). Such “augmented” presentation models are particular suitable in an exhibition setting whereby the landscape model and the layers of information projected make it easily digestible to a wider audience (Nijhuis and Stellingwerff 2011).

Any geo-referenced map can be projected onto the physical model. Here the shaded DSM and animated flood simulation results are projected onto the model.

Since the flood model runs of the same point cloud model used in the fabrication process, the resultant flood simulation results can be projected precisely onto the physical model.

Fig. 5.10: Augmenting the physical milled model with animated flood simulation projections provide for an easily understandable means to communicate the severity and scale of the floods to a general audience.

Indeed the milled model was developed to be an interactive exhibition piece showcasing the preliminary outputs and capabilities of the team. The underlying software tying the projections and interactivity together were programmed in Processing ('Processing.org' 2015), a free and open-sourced programming language, development environment and online community targeted at allowing users to easily generate their own applications. This allowed the simultaneous projections of information onto two difference surfaces, the physical model situated on the table as well as a projection onto the screen behind the model which supplements the information being projected (Fig. 5.11). With this setup, videos, animations, slideshows, maps, diagrams could all exist within the same interactive framework. Interactivity was programmed into a keypad as well as an experimental Leap Motion Controller ('Leap Motion' 2015) which allowed users to use hand gestures to shuffle between categories and subcategories, fast forward animations and pan around the high resolution orthophoto.

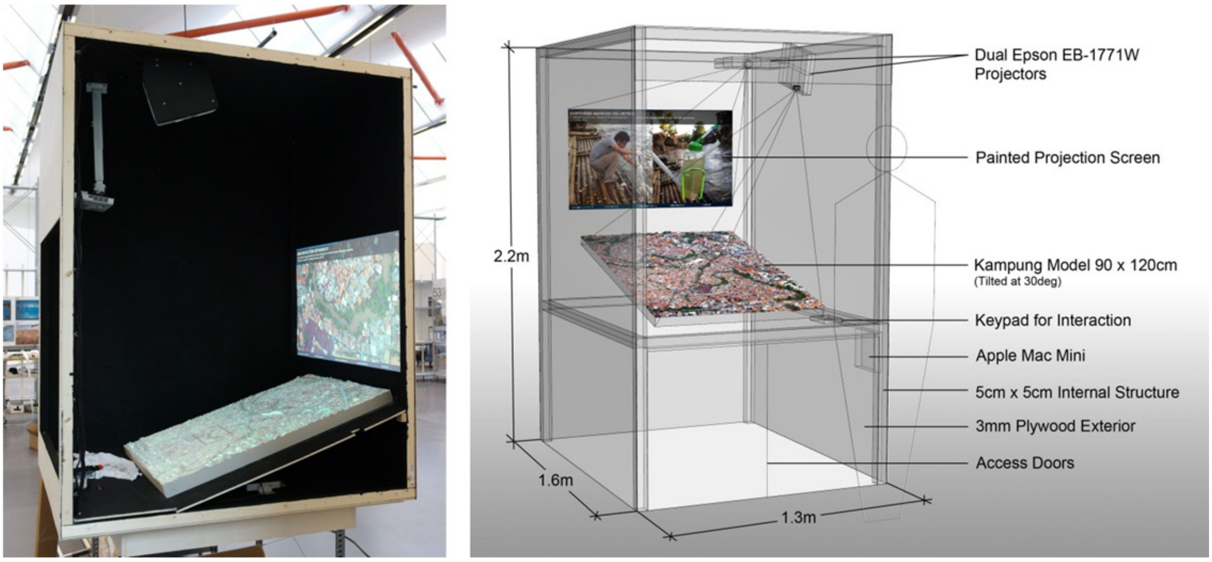


Fig. 5.11: A physical cut out of a booth designed and built for the 2014 International Architecture Biennale Rotterdam showing how two projectors simultaneously projected related information onto both the physical model as well as the screen in the rear.

This interactive booth, often accompanied by an array of other exhibition materials - including a 5m long catchment scale milled model created using the same techniques mentioned above but using satellite terrain data instead - showcased the breadth of work carried out by the team on the Ciliwung River and has since been exhibited in several locations around the world (Fig. 5.12).

Fig. 5.12: Variants of the same exhibition were presented at several cities around the world. These include the "Future Cities Laboratory Midterm Exhibition" at the Singapore-ETH Centre in September 2013; the "2014 International Architecture Biennale Rotterdam" in May 2014; the "Future Cities Laboratory: Research, Outcomes, and Prospects" Symposium and Exhibition" at the ETH Zurich in September 2014; the "Future City Jakarta: Swiss and Indonesian Research and Technology in Practice" Symposium and Exhibition at the Universitas Indonesia, Depok Campus in Jakarta in November 2014; and lastly the 'Future Cities: Research in Action' exhibition at the Urban Redevelopment Authority of Singapore (URA) Centre in March 2015. In all the exhibitions, it was found that the physical models and especially the augmented physical model presented a very digestible format for team members to explain the project to a diverse audience.

While the exhibitions were generally well received and it was clear that the projected flood simulation and other interactive media allowed for a digestible way to showcase the project, the physical model is still extremely static in nature and can only show a single scenario at once; in this case only the original scenario was shown and at a single fixed scale. There is of course a possibility to showcase a series of scenarios at different scales by having multiple milled models with multiple projectors but this significantly increases the cost, time and space required. As such, as a communicative tool in an exhibition setting, augmented models such as those shown here are effective but as a design explorative tool, its static nature, high cost and lengthy production times make it cumbersome and tedious to be used effectively. Interactivity is one possible way which might bridge this gap such as the use of hand moldable clay or sand instead and a system is made to simultaneously scan the terrain and projects simplified hydrodynamic models based on the hand modified model (Hurkxkens and Munkel 2014; Reed et al. 2014). Of course using such an approach would negate the opportunity to leverage off the reality captured point cloud information as it simplifies the terrain into a bare earth clay model. Perhaps a possible way forward in the future is to make such haptic modifications within the virtual world instead of the physical one.

5.2.3 Point Clouds and Virtual Reality

Instead of attempting to manifest the digital 3D point cloud model into the physical world, a process which inherently causes losses in resolution and detail, the thesis lastly explores the inverse option of bringing the viewer into this digital world instead through the use of Virtual Reality (VR). VR is a collection of technologies for generating a human-computer interface that allows the user to become completely immersed in a 3D environment using their natural senses of sight and sound while interacting with this environment using motor skills in real life (Hardiess et al. 2015). Although VR itself dates back to the 1950s, disappointment with the technology drove it into specialized fields and only in the past few years has technological advancements truly made it available to developers and members of the public (Boas 2013). For academia, it has been suggested that the use of VR for architecture, landscape architecture and environmental planning aid in making visual studies between these fields more interdisciplinary - although it was also found that amongst the three, landscape architecture had the least applications of VR which explored proposed scenarios as opposed to existing ones (Portman et al. 2015).

A variety of devices have been created for the purposes of the immersion demanded in VR, the head-mounted display (HMD) is perhaps the one which has been gathering the most interest in the press. HMDs use stereoscopic displays and tracking systems enabling the user to not only view the digital environment in 3D but to look around it as the virtual camera follows the user's head position. Leading this new revolution of HMDs was the development of the Oculus Rift HMD ('Oculus VR' 2015) (Fig. 5.13), positioned to be an affordable wearable device originally designed for computer gaming entertainment but has since been adapted to a variety of other uses as well (Heaven 2013). While years in development, the prototype HMD and the associated developer software has already been made available and can now be directly interfaced with Unity ('Unity' 2015). Unity is a flexible and powerful development platform for creating games and interactive applications and it is a relatively simple affair to create an interactive digital environment from reality captured point cloud data - a method has already being used to visualise architectural models (Tschirschwitz et al. 2014).

Fig. 5.13: Colleagues trying out the Oculus Rift Head Mounted Display unit took only minutes to learn how to navigate themselves within the virtual environment.

For point clouds, there is still no native support in Unity and a workaround plug-in is required ('Point Cloud Viewer and Tools' 2015) which has a technical limit to the maximum number of points displayed, this is further crippled when the display is fed through the Oculus Rift which then introduces lag and other optical anomalies. Despite these limitations, it is still possible to use the reality captured point clouds to create an immersive VR experience using Unity to build the application which feeds the Oculus Rift. This displays the digital landscape in stereo with character mobility handled using the keyboard and mouse - much like a first person video game. The resulting experience is one where the user can repeatedly revisit documented sites, viewing it from angles otherwise impossible in the real world or to traverse over the landscape to study the topographical changes along the riparian corridor (Fig. 5.14). Nuances in the landscape become much more apparent in stereo vision especially so along the river corridor where the topography of the river banks is easily legible and immediately registered by the user when viewing the model through the HMD. These minute changes in the topography are much more readily apparent than having to read and understand 2D topographic lines or graduated maps typically used to represent height.

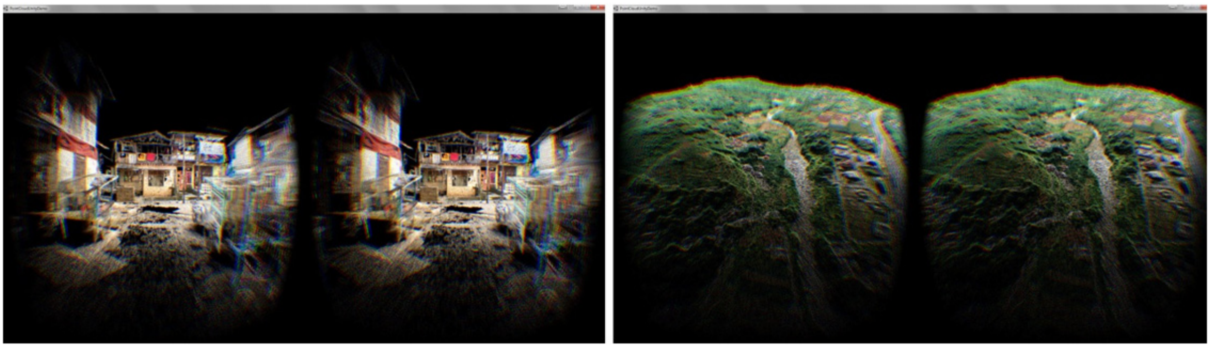


Fig. 5.14: The Oculus Rift projects two images - one to each eye to create the illusion of depth - used together with Unity, reality captured point clouds can set the stage in these virtual worlds for which the user explores from a first person perspective.

This experience while realistic is one which remains surreal and slightly disorientating because of several reasons, some of which are valid even when viewing the point clouds outside of the virtual environment:

- The user does not "walk" over the digital point cloud model but rather "flies" around and through it as the point clouds do not support the collision detection required to simulate the effects of gravity and obstacle detection. While this works well when viewing point clouds covering large areas where the user has an overview of the terrain, ground level virtual walkthroughs through streets feel less realistic as the user is not grounded to the site but floats weightlessly through it.
- The ground, trees, walls, and other objects have an immaterial translucent quality to them (Bhattacharya 2013) as the points spread out and seem to disappear as the user moves closer to inspect them. This "ethereal" nature of the point cloud causes problems when the viewer attempts to move closer to inspect it for finer details. Instead of becoming clearer, the point cloud dissipates as the camera zooms in, making it not only counter-intuitive but also confusing as objects in the background become more visible than those in the foreground (Fig. 5.15). This phenomenon can be slightly alleviated by increasing the visualised point size but additional level-of-detail filters need to be implemented which automatically adjust the density and size of points based on their distance to the viewer.

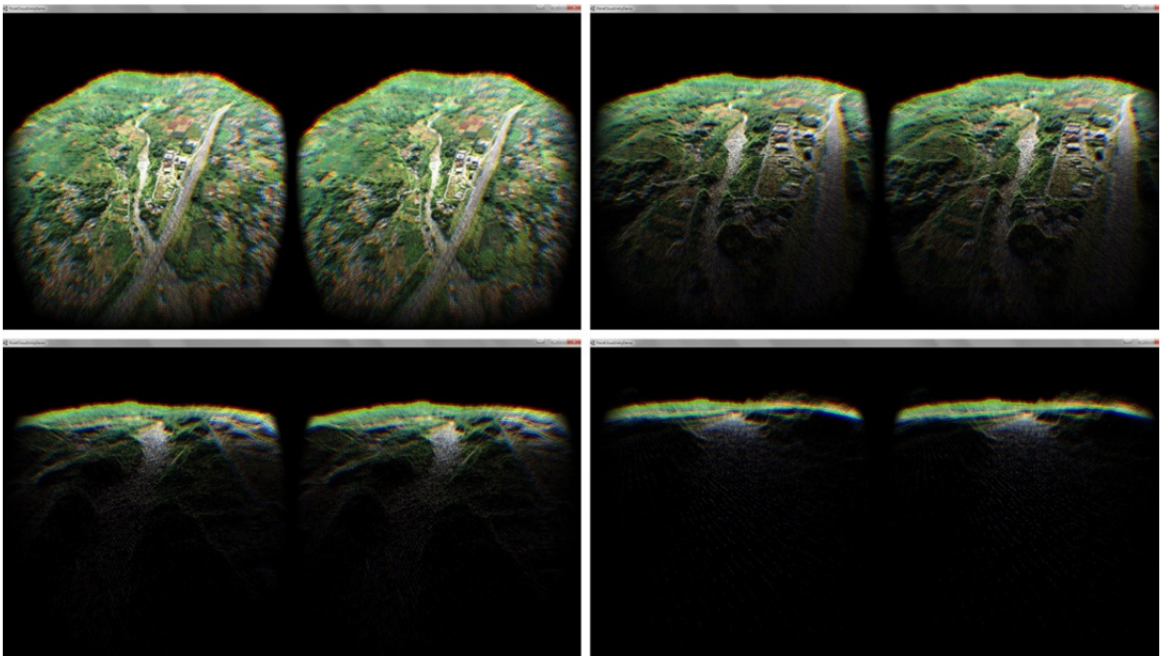


Fig. 5.15 While the point cloud models look realistic when viewed from far, the lack of resolution in the point clouds means that the model "disappears" as soon as the user approaches it for closer inspection.

- While the screen of the Oculus Rift is of a very high resolution, looking at the point clouds through the HMD over extended periods of time is very taxing on the eyes and the brain. This is further exasperated by the way in which the points flicker as they are rendered in the display. As a result fatigue and even motion sickness start to sink in within minutes of usage, as was experienced both by the author and by users of the system.
- Landscapes are said to comprise of six essential elements – landform, vegetation, water, structures, animals and atmosphere – with the last element, atmosphere being critical for visualisations and renderings of digital landscape models (Ervin 2001). Atmosphere is sorely missing in these virtual point cloud environments, there currently is no way of lighting the point clouds, as such sunlight simulations are not possible, nor is it feasible to add in an artificial sky as the user will be able to see it through the point cloud due to its translucent quality. Water in this case is either static or missing from the collected data as flood simulation results have not been animated in this virtual environment, which makes the element of experiencing time within the virtual model impossible.
- This inability to replicate the effects of wind, light, water and other atmospheric phenomena mean that the virtual environment demonstrated here is thus just as static as it was with the physical models previously presented. There is currently no means to dynamically alter the landscape, to plant trees or to widen the river in this virtual environment. Although this would certainly be a possible direction in the future as the users hands can now be projected dynamically into the virtual world as well, opening the possibility for virtual interactions with digital objects (Colgan 2015).
- Lastly, as a communicative tool VR has its limitations, the HMDs make it difficult to share the experience with a large number of people at once. Unlike the augmented physical model discussed before, this is a purely individual experience as at present only one person at a time is able to use the HMD. Here the alternative would be to invest in large and expensive facilities to bring about an all-

compassing viewing experience, an investment which needs to be carefully considered as there are still lingering questions to the efficacy of adopting VR in design fields (Portman et al. 2015).

Despite these issues, VR remains an active and interesting topic for discussion as it has already found a place in a variety of fields of applications, such as the military, medicine, research and of course it's most talked about role in digital entertainment for which the latest VR hardware and software have been developed around. In the near future entire rooms will be made into virtual spaces for which users who don on a HMD can immerse themselves in for entertainment or research purposes alike (Moon 2015; Robertson 2015).

While it is evident that there is no universal landscape visualization solution, selecting the appropriate technique very much depends on the particular task at hand (Lovett et al. 2015). As such, it is highly unlikely that point clouds will replace any of the traditional methods but should be seen as an additional category by itself with its own place within the mirage of possible ways to represent landscape architecture. It is certain that the technicalities and workflow of obtaining and visualizing reality captured point clouds will continue to improve, resulting in a transformation of the way we obtain spatial data of our environment (Chapter 5.5.1), however for point clouds to become a mainstream representative format for landscape architecture, the development of much more robust tools and an entire hardware and software ecosystem catered specifically to it will be required (Chapter 5.4.4).

5.3 Point Clouds as a Performative Format for Landscape Architecture

5.3.1 Hydraulic Simulations

The thesis has demonstrated the definite possibility of developing point cloud based scenarios from reality captured data and integrating them with hydraulic simulations. This capability was particular pertinent when dealing with the Ciliwung River as the work required the ability to predict the impacts a variety of scenarios would have with regards to the issue of flooding. In both the site and corridor scale scenarios, hydraulic simulations were successfully run and the results helped highlight the advantages and disadvantages of each scheme. Using the augmented site scale models in an exhibition setting previously discussed in 5.2.2, these results have also been shared with members of the public in several different countries bringing to light the issues faced by the residents along the ailing river. The corridor scale scenarios - while not prescriptive enough to be implemented in the real world - are able to provide an insight into the potential dangers of proceeding blindly with the government's plans to fully normalize the river while seeding the idea that an alternative approach might be possible (Elyda 2015). To this end, the thesis has shown that point clouds can indeed act as a performative format for landscape architecture projects dealing with problems of flooding, what is required now is to identify and address the issues in this workflow:

- Obtaining reliable and accurate input data is an important first step. While it is possible for a landscape architect to do this himself, technicalities behind the process mean that this procedure of obtaining and processing of the raw input data is often out of his control and the subsequent accuracy of such data remain difficult to control and verify. The initial UAV mission needs to be calibrated and requires proper support from ground based GPS teams while the production of a reliable DTM requires hours of manual work by an operator. These, together with obtaining the permission to operate the UAV (Chapter 5.4.5), require months of preparatory work during which the riparian landscape along river might already be altered dramatically (Chapter 4.4.4).
- Ideally the simulation results from a given scenario would have been used to refine the proposed interventions in an iterative loop until the most suitable solution is found. However, in all cases demonstrated, the loop was never closed and the experiments ended with just one set of results for each scenario. In the case of the students design-led scenarios at the site scale, issues with learning to modify the point cloud as well as the eventual time required to run each simulation meant that the results reached the students only at the end of the semester leaving them with no opportunity to further refine their designs. Similarly at the corridor scale, it took up to a week to run the simulations for each scenario – even with the developed parallel version of 2dMb. This, coupled with the need to run multiple simulations to obtain a representative flood, meant that the final results took several weeks to obtain. While this might be less of an issue if more powerful parallel computers were used or the code was further optimized (Chapter 5.4.3), the fact is the speed in which the simulation results are returned are at present too slow to enable an effective iterative design loop.
- Disregarding the issue of speed and the realities on the ground, specific results from the simulations were meant to be studied such that localized fine tuning of the proposals can be made. For example, accurate indications bed shear stress could allow for designs to cater for different bank treatments at different locations. Banks which undergo low stress are likely candidates for the establishment of

vegetation as erosion is less likely to erode away the soil before the vegetation takes root. Conversely areas of high stress could be dealt with more robust bank reinforcements such as gabion walls or even concretization if so required. Unfortunately there were anomalies in the simulation results which provided information contrary to what is understood of the erosive behavior typical at river meanders (Fig. 5.16). This meant that attempting to use these results to further refine the design of the river banks would come under question. While the issue was highlighted to the engineers in the team, no resolution was made towards the end of the project.

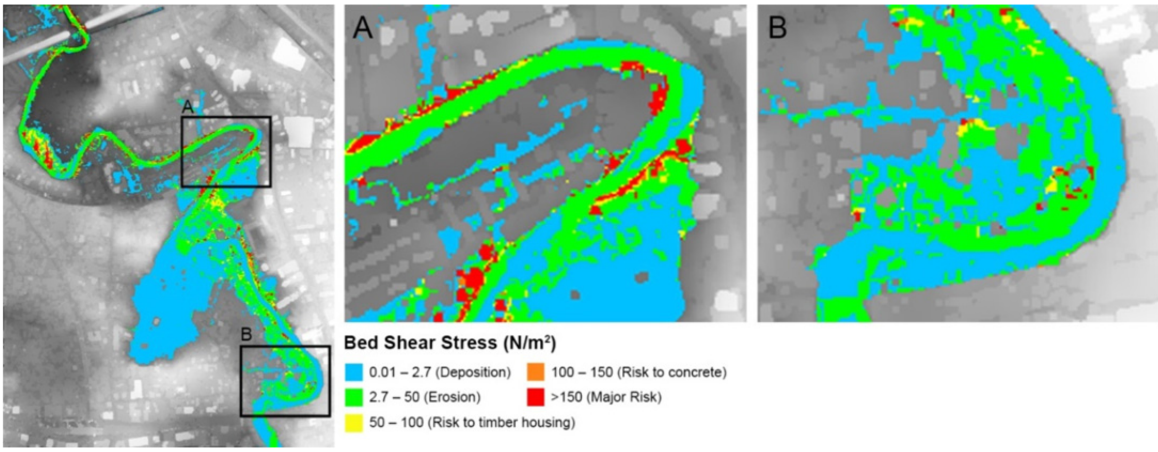


Fig. 5.16: The general understanding of where erosion and deposition occur when a river meanders seems incorrect in the bed shear stress maps generated. Here instead of erosion occurring on the concave bank and deposition occurring on the convex bank, the opposite is happening.

- Currently while the point clouds exist in 3D space, the simulations are not able to handle more complex three dimensional obstacles, such as flowing under bridges or dispersing through riparian vegetation. This presents problems when attempting to prescribe alternative solutions such as floodable architecture or parks as the inclusion of any objects would be seen as a non-permeable solid obstacle. The current workaround used was to artificially lower the heights of buildings to prevent them from being solid obstacles or to completely remove other obstacles such as bridges and trees (Chapter 4.4.3). In addition, there was no inclusion of the ability to dynamically divert flood waters through gates, pumps or other possible controllable infrastructural solutions which might have led to other proposals which have the potential to further alleviate the flood.
- The point cloud models used for the flood simulations are arranged in a regular grid, as such there is a minimum size in which interventions will register in the simulation and objects smaller than the grid size are not able to be accurately represented. This means that the columns of buildings and bridges, tree trunks, drains and other smaller obstacles might be completely obscured simply because their footprint is smaller than the grid size. Yet decreasing the grid size might not be a possibility as well; firstly, the original data collected is already of a particular resolution and trying to increase the resolution can only be done through interpolation; secondly, as the resolution increases, so does the number of points, resulting in an exponential increase in the time taken to run the simulations. Understanding this issue, a suitable grid size needs to be decided upon based on the size of the intervention planned even before the collection of data to ensure that the collected data either matches or exceeds the desired resolution.

- As discovered in chapter 4.3.5, the addition or removal of riparian vegetation seems to play an insignificant role in the flood simulation. This might be due to the fact that vegetation is only represented by a difference in the friction value of a cell without any other additional mathematical models which are specific to simulating the effects of vegetative cover. Other factors such as infiltration or bank stabilisation which might occur when riparian vegetation is established are unaccounted for. Thus a more robust vegetation model needs to be developed in order to more accurately reflect the actual effects riparian vegetation might have on more than just their flood mitigation potential.
- Finally, the cumbersome method in which the existing workflow requires exporting the classified DTM for use in 2dMb, running the simulations through a command line interface and eventually reimporting the results one file at a time hinders the fluidity of the workflow. This tedious process of exporting and importing, along with the multitude of file types to deal with could be streamlined in which the boundary conditions, hydraulic inputs and outputs are all available from a single tool within Rhinoceros or any other modelling software (Chapter 5.4.4). The results of which should be stored in a format which allows for custom metadata (Chapter 5.4.2) to be dynamically visualised in order to quickly scan through the animation to identify not only areas of interest but also to explore the chronological dimension of the flood wave propagating through the landscape.

In addition to these issues, the degree to which hydraulic simulations can integrate, or better yet couple, with point cloud model scenarios is largely reliant on the level of cross disciplinary collaborations. These collaborations between the design and engineering fields require a fair amount of coordination to ensure that a whole series of technicalities are aligned together – such as file structures, resolution, boundary conditions as well as other limitations on either side. Beyond these technicalities, a common ground needs to be established in which the two disciplines interact, leaving behind their epistemological differences while bringing their own expertise to the table. In the case of hydraulic simulations presented in this thesis, the common ground here was the scenarios created in the form of a gridded point cloud model with the respective friction values attached to it. This gridded point cloud model appended with additional metadata is a likely candidate to interface with an even wider array of disciplines in order to enable other forms of quantitative assessments on the developed scenarios.

5.3.2 Landscape Metrics & Other Possible Performance Indicators

One other quantitative assessment performed on the developed corridor scale scenarios was the calculation of landscape structure using landscape metrics in an attempt to find any correlation between the results from the selected metrics and those from the hydraulic simulations. Simply put, the thesis set out to discover if quantifiable changes in the quantity, configuration or spatial distribution of the riparian vegetation would correlate with the flood simulation results in a significant manner. While it has been demonstrated that the scenarios can indeed be quantified by landscape metrics using FRAGSTATS (Chapters 3.4.3 & 4.3.6), it was not possible to uncover any correlation between the metrics and the flood simulation results due to the fact that the latter seemed insensitive to changes in riparian vegetation (Chapter 4.3.5). As a result, it is likely that even an extreme hypothetical scenario of a completely reforested landscape would significantly skew the metrics but have no significant changes to the flood simulations. To reiterate, it is not so much a problem with landscape metrics itself, but rather the inability within the findings of the thesis to correlate results from the flood simulations with those from the metrics calculations. Since such a correlation could not be established, the thesis then found it difficult to make sensible use of the metrics to inform further design decisions which was further hampered by several other underlying issues:

- The main input for use in calculating landscape metrics using FRAGSTATS is that of a classified 2D map which is carried out after the base data is collected. This presents a potential issue as the accuracy of the classification process greatly influences the results of the calculated metrics. Considering that the thesis only uses colour and height information to extract this information, a degree of inaccuracy is bound to follow (Fig. 5.17). Unfortunately without using cameras capable of capturing data from non-visible spectrums, this remains the only feasible method other than extensive fieldwork or tedious manual classification.

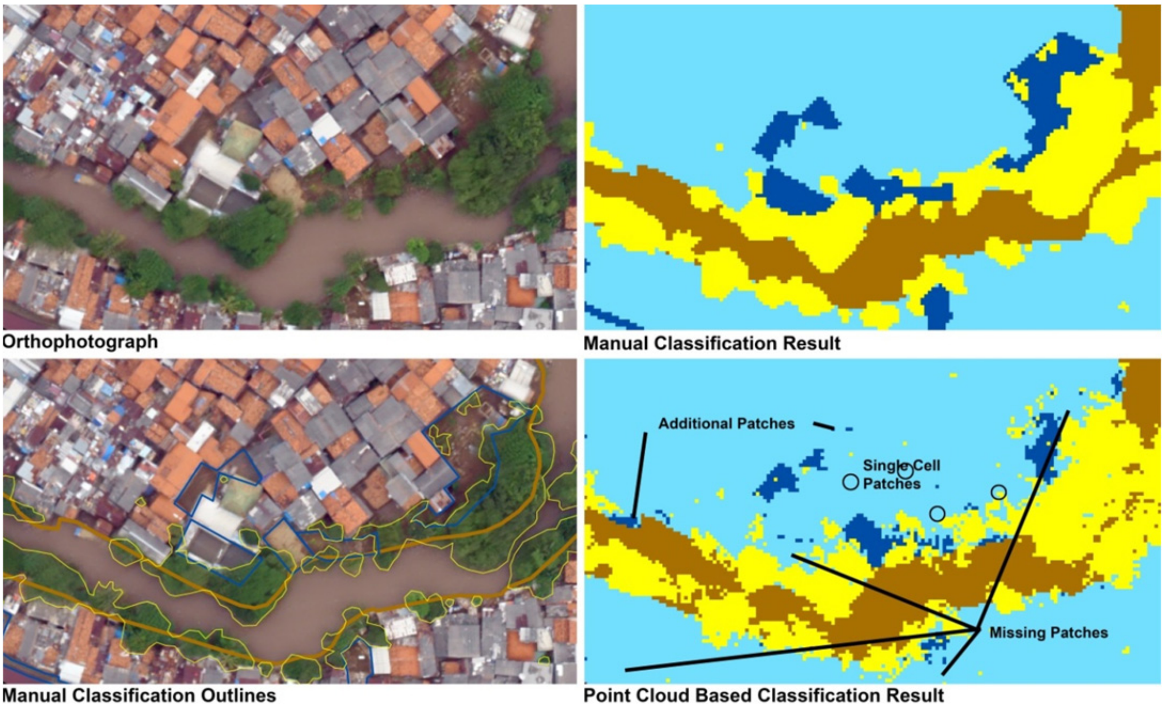


Fig. 5.17: A close up of one of the classification maps show the errors which show up when comparing between a manual classification approach - in which outlines of LCTs are identified by observation of the orthophoto – and the point cloud based classification approach - in which colour and height information are used to classify the point clouds.

- The flattening of the landscape into a 2D gridded map neglects the differences topography and the realities on the ground. FRAGSTATS is fundamentally a two dimensional software, as such it is not capable of processing more than a single classification type per grid cell nor can it analyse height information. The inability to process more than one classification type per point also means that occlusions and overlapping LCTs such as bridges or trees covering the river can affect the eventual results as one LCT has to be chosen over another. This also means that any calculations which intend to include topography are impossible although topographical changes in the landscape can indeed form a very clear boundary or conduit for ecological processes.
- As a design driver, the thesis found much difficulty in attempting to use the results derived from landscape metrics to influence iterations of future scenarios. Landscape metrics here were used to cross reference different developed scenarios, and indeed there was a positive correlation between the results and the changes made to the scenarios (Chapter 4.3.6). However, this neither informs the designer any more other than what they already understand of the changes they made to the different scenarios nor are there developed guidelines or targets for which each individual metrics should obtain in order reach sustainable or ecological goals. In essence, the numbers mean little to landscape designers. An issue which relates back to some of the fundamental issues with using landscape metrics as a means of understanding the landscape from a designers perspective.
- There is an underlying debate ongoing revolving the use of quantitative landscape ecology. Specifically, the patch matrix model (PMM) used in this thesis is essentially a very simplified conceptual model representing a limited aspect of the underlying realities of the actual landscape. The PPM which has been the cornerstone of quantitative landscape ecology has since given way to growing

skepticism about its suitability to establish relationships between landscape structures and ecological processes (Lausch et al. 2015). An alternative to the PPM is the Gradient Model (GM) (McGarigal and Cushman 2005) which is more complicated to work with but are able to negate the issues of over simplified aggregations and assumptions faced by the PPM by leveraging on the raw outputs of remote sensing data. Considering that the GM represents landscape structure as continuous data in form of a grid, with each cell in the grid being embedded with an additional third dimension, it would seem that exploring point clouds as a format for GM analysis could be yet another avenue for further research to be carried out.

Similar to how a great deal of collaborations with the team's engineers made the hydraulic simulations not only possible but effective, working in conjunction with ecologists might have provided greater insights into using landscape metrics as a potential performative testing platform. Perhaps these issues would have been ironed out more readily if the team had an ecologist working with quantitative landscape ecology during the course of the work. The same will be true when attempting to use other potential performance analytical tools. Such tools to calculate landscape performance always focus on particular topics, such as those collated by the Landscape Architecture Foundation under their "Benefits Toolkit" (Landscape Architecture Foundation 2015) which bring together tools and calculators to be used to estimate specific landscape benefits for completed or potential projects. These include tools which estimate the valuation of ecosystem services, quantify the environmental and aesthetic benefits of trees, determine the value of green infrastructure, help in determining rain water management, provide for waste reduction models and other relevant performance indicators. Unfortunately these tools are currently all standalone products, with some being web-based calculators while others are pre-prepared excel spreadsheets which would mean that each tool would need an additional translation from design intent into a format for these measurable performance indicators.

5.4 Technical Challenges Ahead

5.4.1 When 3D is actually 2.5D

While point clouds exist in a 3D space, the input data used in this thesis collected from the UAVs and satellite imagery, as well as the subsequent analysis with hydraulic simulations and landscape metrics actually exist in a 2.5D format - in which the x and y coordinates exist in the form of a regularly spaced grid with each grid cell appended with additional height or classification information. For visualisation, this 2.5D format means that building facades, tree trunks and other vertical surfaces are missing with only the top most surface acquired in the collected data. While this issue might not be so critical for some sites, at others the missing facades gives a false impression on the lack of solidity of vertical structures and landforms and erodes the realism produced by such reality point cloud visualisations (Fig. 5.18).

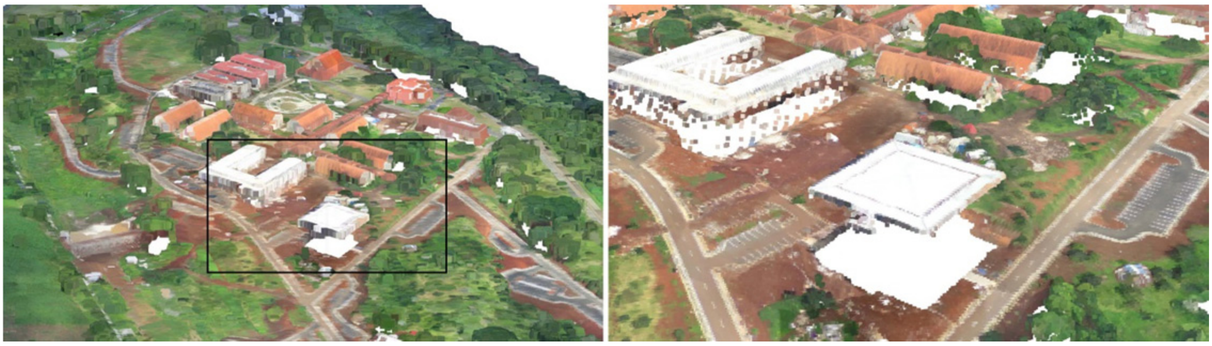


Fig. 5.18: Depending on the distance at which the digital landscape is viewed as well as the type of objects within the landscape, the lack of data from vertical surfaces can break up the otherwise visually contiguous model. This often manifests in missing facades and undergrowth making roof structures and tree canopies float awkwardly above the ground.

Similarly, both hydraulic simulations and landscape metric calculations allow only the importing of a 2.5D gridded model, not a truly 3D one. As previously mentioned, for hydraulic simulations this means that water is not able to flow under or through obstacles such as tree canopies, bridges, pipes or buildings. This not only limits the way in which the model has to be prepared but also the possibilities of alternative solutions such as an underground diversion channels or purpose built floodable architecture. For landscape metrics this issue is further exacerbated as the point clouds are exported without any topographical information at all. Treating the landscape as a two dimensional abstraction also fails to include how drastic changes in the terrain, such as cliffs or steep banks can just as likely influence the mobility of species across the same patch.

While this additional information can be obtained if oblique images were collected during the UAV mission or supplemented by ground based collection methods, this would have entailed a much more complex operation quickly inflating the size of the point cloud and the subsequent processing time. In the same light, attempting to solve hydraulic simulations or quantify landscape structure in this additional third dimension will not only require a complete rework on the underlying code but even when done so will significantly increase computation times. However, the thesis believes that pushing for a truly 3D base dataset is a necessary step forward not just for representational purposes but also to run analysis in a three dimensional fashion and to do this more effectively, the point clouds need to be able to have additional custom metadata appended to them.

5.4.2 The Need for Embedded Custom Metadata

Point cloud data exists in different formats depending on how they were captured or created as well as a result of different proprietary file formats used by companies, each with their own software packages. This complication in the variety of formats has resulted in an ongoing effort by the Open Geospatial Consortium (OGC) and the American Society for Photogrammetry and Remote Sensing (ASPRS) to set standards in which point cloud data is acquired, disseminated and processed (Open Geospatial Consortium 2015). Regardless of the technical differences, all formats would essentially consist of a table of data holding the coordinates of each point as well as the associated metadata or attributes appended to each point. In this thesis, point clouds were explored only within Rhinoceros whose native point cloud format has only a fixed number of attributes. In comparison, public file formats such as LASer (LAS) which is typically used for LiDAR point cloud data allows not only for the interchange of 3-dimensional point data but also the customization of additional point classes and attributes on top of the native LiDAR data (ASPRS 2013). It is anticipated that this ability to embed custom metadata into the existing point cloud will enable a much wider range of performative analysis to be more readily conducted on the point cloud. This is a result of the discrete nature of the points within the point cloud from which, instead of having to convert into intermediate formats while shuffling between software packages, the extraction of coordinate information together with the required attribute information can be done through the process of querying and extracting the required points from the table of point data to feed into the respective quantitative models.

Growing with this desire to set standards across the industry, there is also a rise in the number of tools which are being developed to work with point cloud data - such as the Point Cloud Library (PCL) (Rusu and Cousins 2011) - an open source software package consisting of a number of algorithms to work with point cloud data; Point Data Abstraction Library (PDAL) (Butler et al. 2015) – a C++ library for translating and manipulating point cloud data; FME (Safe Software Inc 2015) – a commercial software which is capable of processing and transforming point cloud data for use in other applications; LAStools ('LAStools' 2013) – an efficient collection of command line tools used to run a variety of operations on LiDAR data. These and other software packages are standalone utilities but researchers have already begun interweaving them together in a desire to leverage off the unprecedented detail provided by reality captured point clouds using the processing power provided by high performance computing (Netherlands eScience Center 2015).

5.4.3 High Performance Computing Necessity

A constant issue throughout the thesis has been the fact that the sheer size of the point cloud data severely slows down both the visualisation and, to an even greater extent, the underlying algorithms used to modify the point cloud models. While point clouds have been found to make more efficient use of available memory as opposed to surface models owing to the fact that they exclude the surfaces and triangular meshes which increase processing time as well as storage complexity (Linsen 2001), modern methods of reality capture push the number of points in a cloud easily into the millions if not billions of points. The height map of the Netherlands (Actueel Hoogtebestand Nederland 2015) for example, consists of 640 billion height points stretching the size of the data into the terabyte range. Dedicated point cloud visualisation software packages might be able to handle such large datasets but the 3D viewport in Rhinoceros is simply unable to handle point clouds of this size. In addition, while the tools created were written with simple parallel codes, increasing the number of points exponentially increases the amount of time required to run them while having to deal with additional metadata would only serve to further exacerbate the issue.

Fortunately, this issue of the difficulty in working with large point cloud datasets is already being tackled by researchers in the computing disciplines. Here, advances have been made in the analyzing and visualizing "massive point clouds" by leveraging off graphics processing units (GPU) (Richter and Döllner 2014) and using database management systems (van Oosterom et al. 2015; Martinez-Rubi et al. 2015a) which allow the establishment of these as the base datasets from which to work off. Similarly, parallel programming needs to be extended to the performative models (similar to what was done with a parallel implementation of 2dMb) such that processing times are reasonable enough for design purposes. The thesis thus envisions the possibility of realizing a unified software package - with point cloud data at its core - that is built upon the back of high performance computing while developed within a spatially georeferenced environment.

5.4.4 Hypothetical Unified Platform with Integrated Tools & Models

While a preliminary set of tools were created for the demonstrative purpose of the thesis, much more sophisticated modification and visualisation tools which integrate with performance testing models are required to enable point clouds to function simultaneously as a representative and performative format for landscape architecture. The thesis envisions a modular set of database management, modifying, testing and visualizing tools built under a single software platform with the capability to rapidly process, store and retrieve acquired raw data; dynamically modify the geospatially referenced digital landscape; integrate with quantitative assessment models; and finally visualise both the point cloud data as well as testing results (Fig. 5.19). The base point cloud model here provides the unifying spatially referenced three dimensional baseline data from which all other design ideas can be formulated and eventually tested.

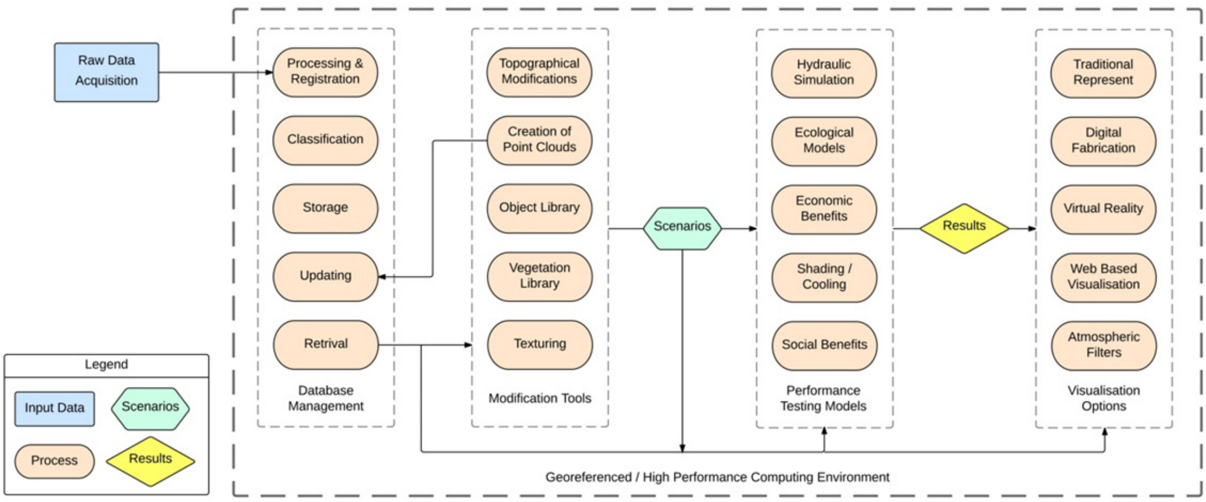


Fig. 5.19: A flow chart of the hypothetical software platform which would be built upon a georeferenced and high performance computing environment and have the capability to manage large point cloud datasets, the availability of tools and models to modify and test them and finally to visualise them through various means.

The first task at hand is to provide the parallelized hardware and software infrastructure which allows efficient processing of acquired raw data and to store them in a way which caters for dynamic retrieval and updating. This processing and retrieval will need to take into account the fact that data acquisition would likely be obtained from a variety of different sources, at different times and at varying scales - all with the possibility to append additional metadata to the data. As such the tools and workflows need to be able to not only facilitate the registering of different point cloud models into the same georeferenced environment but also to do so with chronological data appended to it as well. This should include not only the point clouds which are those collected through reality capture but also those which are created through the modification process as well considering how some information might need to be manually injected. For example, the terrestrial or aerial platforms used by the thesis were unable to record the bathymetry of a river, thus interpolated physical measurements were used instead to create a point cloud representation of it. These created point cloud models fill the gaps missing in the reality capture ones to produce the base point cloud model from which further modifications can occur.

For point clouds to serve as a representative format, the tools used to modify the point clouds need to become more intuitive, allowing for a much more rapid "molding" of the digital landscape. This includes the ability to quickly alter topography, create new point clouds, add texture and place a variety of elements into the landscape in virtual reality or otherwise. This is especially so for vegetation where a point cloud based vegetation library is required to quickly and effectively model the desired vegetation across the digital landscape. This would likely be in the form of a parametric model in which an area is identified and parameters such as the species, density, age and other factors generate the representations required automatically. Vegetation modeling and visualisation software packages that are able to do this have long been in existence. Originally created by researchers (Muhar 2001) such software packages have since evolved tremendously to ones which are commercially available to the public, such as Laubwerk (Laubwerk 2011) which was used by the students to produce their final visualisations. However these representations of vegetation are neither created in the form of point clouds nor are they meant to interface with performance testing models, but instead are ultimately designed for visualisation purposes only. In comparison the thesis proposes that the point cloud vegetation models should not only be visually representative and biologically accurate, but also needs to have embedded metadata which informs of their hydraulic or ecological values currently represented in the thesis only by friction or classification information.

To be able to run more accurate quantitative analysis of the proposed scenarios, it is necessary to develop or adopt more complex mathematical models which have the capability to accurately predict the possible effects of vegetation (Camporeale et al. 2013) such as the impendence to flow, infiltration into the ground, erosion prevention, ecosystem services valuations and other known attributes. Coupling these complex models with the vegetation library would mean that the parametrically created point cloud models of vegetation would already have the required metadata information embedded within them to streamlining the representation to performance testing process. The same might be possible for other potential performance indicators such as shading or cooling, wind deflection, rainwater harvesting and possibly even other quantifications of economic, social and environmental benefits. Such performance testing models should be built within the same hardware and software ecosystem in order to be able to retrieve and process the point cloud data and visualise the results from these testing processes all within the same environment.

The software also needs to be able to handle visualisation of the base dataset, the scenarios generated as well as the results from testing. Within this visualisation package should be the inclusion of atmospheric filters such as the casting of light, animation of water or wind as well as means to publish these through a variety of platforms.

This would include the already discussed possibility of materializing the data in real life through digital fabrication or the inverse by using virtual reality and the possibility of publishing the data onto the web to communicate the information to a much wider audience. This is now a possibility by using free and open-source renderers (Martinez-Rubi et al. 2015b) to view massive point clouds over the internet on any web browser. Soon it might even be possible that these extend beyond a purely visual representation into one which can be dynamically altered over the internet by a variety of stakeholders.

Hopefully in the near future these tools and models will be incorporated into a single expandable platform - either as an expansion of an existing software package or a completely new one created from scratch – that is built specifically for use with point clouds, able to couple with performance testing modules and is capable to handle true 3D data with the help of high performance computing. Understandably this shift from the 2D GIS paradigm into a 3D one will not occur overnight as it requires a huge investment in resources to not only obtain the data but to build an entirely new ecosystem around it ranging from developing new storage servers, rewriting algorithms originally used for 2D data, as well as the training of end users to adopt this new workflow (Chapter 5.5.3).

5.4.5 Legality, Safety and Ethical Issues

While the issues above mainly point towards working with the raw input data, collecting the data itself is starting to become a potentially sensitive topic, especially so with the use of UAV technology. Originally found only within the domain of the military, UAVs have in the past decade been more rigorously used by researchers for a range of different environmental applications to obtain increasingly accurate data at much more affordable prices, but not without a degree of ambiguity about their regulatory restrictions (Paneque-Gálvez et al. 2014; Colomina and Molina 2014).

Issues on the legality, safety and even ethics on the use of UAVs have become regular news in the mainstream media, often putting UAVs in a bad light (Foster 2015). The bulk of the news has been in the form of proposed or implemented regulatory guidelines which were a direct response to the perceived threats civilian operated UAVs pose and in more recent reports the possibility of drones being used by terrorists (Hambling 2015). In the United States (US), the Federal Aviation Administration (FAA) has recently announced a new proposed registration requirement for all Unmanned Aircraft Systems (UAS) (U.S. Department of Transportation 2015). Citing incidences in which UAS have been operated in an unsafe manner disrupting major sporting events, manned aircraft flights and even wildfire operations, the FAA hopes that this registration process would bring about greater accountability in UAS operators. This registration might even include toys (Atherton 2015a) and might go so far as to make the names and addressess of the registry public (Walker 2015). While there are sources from which members of the public can look to for guidance (Landforce 2015; Know Before You Fly 2015), the rules and laws in the US are still hazy and the lines drawn between what is considered a UAS or the difference between recreational and commercial use are still debatable.

While the FAA in the US are still preparing guidelines, Singapore has rapidly taken steps to pass laws which regulate the use of UAVs (Fig. 5.20) with permits being required depending on the weight of the UAV and its intended purpose, along with clear demarcations on areas UAVs are restricted from flying (Lee 2015). Japan has likewise made amendments to their Civil Aeronautics Laws which limit the use of drones, going so far as to setting up an "anti-drone" squad in Tokyo to physically bring down unlicensed drones in the city (Atherton 2015b). Thailand went one step further in recommending imprisonment and a fine for unlicensed drone flights, including those by individuals for recreational purposes (BBC 2015b), a reaction which some see as means to control the use of drones as a powerful journalistic investigative tool (Greenwood 2015). Similar concerns on safety and privacy have led to regulations being put in place in other countries in South East Asia but the exact details vary from country to country (Parmar 2015). As such, researchers seeking to utilise UAV technology for such purposes need to be extremely diligent in ensuring that they obtain the necessary permits and understand that UAVs inherently carry a degree of risk which needs to be carefully weighed.

Fig. 5.20: A flyer that was mailed to every household in Singapore graphically indicating the regulations being put in place with regards to the operation of UAVs (Civil Aviation Authority of Singapore 2015).

Of course UAVs are not the only means of obtaining point cloud data of the landscape, other methods of collection are still possible - which are unlikely to raise as much controversy - such as terrestrial LiDAR. In fact, in places like Australia it is easier to obtain the permits to operate a manned helicopter than it is a UAV (Byrne 2015). Understandably each method has limitations, such as safety, cost, portability, range, reliability and accuracy, which need to be weighed in carefully before picking the right equipment for the task at hand. Perhaps an ideal situation would be to have governmental agencies provide open or restricted access to high resolution aerial and terrestrial laser scans to end users thus negating the need for them to have to obtain the data themselves.

One way or another, it is clear point cloud data can be obtained of our landscapes and it is just a matter of time before this mining of geospatial data, hardware, tools and software packages developed to enable efficient use of point cloud data becomes a reality. At present the technology is already mature enough for us to begin further explorations of the efficacy of adopting a point cloud workflow and it is at this junction which the thesis postulates on the possible role in which point clouds might play in landscape architecture in the near future.

5.5 Point Clouds and Landscape Architecture

5.5.1 Changing the Way We Obtain Baseline Topographical & Spatial Data

The release of Google Earth in 2005 sparked a shift in the way architectural and urban responses have operated in increasingly complex urban conditions (Scott 2010). Previously the purview of governmental or military agencies, tools like Google Earth transform the way we obtain information about the world around us with an intuitive, interactive, multi-layered, high resolution database of our entire planet that has now become a staple of students and practitioners alike. Google's belief is that information technology has enabled the "democratization of data" (Varian 2008) and allows information to reach people who were previously never able to. It was anticipated that the emergence of the technologies discussed will allow us to capture reality into digital earth models (Gruen 2008) and reality captured 3D models have already started to populate certain cities within Google Earth. It is these advancements which the thesis believes would be the next evolutionary step in the "democratization of geospatial data" and change the way landscape architects obtain baseline topographical and spatial data.

Even when such data is not publically available, reality capture technology is not only getting more accurate, more importantly it is getting more cost effective and making its way into the hands of anyone who wishes to use it. While the technology available to end users is still in its infancy, landscape architects can now collect high resolution geospatially accurate and representationally credible data of the landscape with much greater ease than ever before. They can do this using an arsenal of equipment from the simplest digital camera to a ground based LiDAR scanner to an aerial mapping UAV. This is especially useful when working in areas with a lack of accurate or up to date publically available data as shown in the thesis. Landscape architects should begin to adopt this emerging technology to obtain information about our landscape and in doing so challenge the way established methods of collecting, visualizing, manipulating and analysing of baseline topographical and spatial data.

Once successfully collected and processed, the digitized point cloud landscape takes center stage and serves as the springboard for design work where the landscape architect can repeatedly revisit to discover, measure, and test the digital landscape in ways previously unavailable through traditional two dimensional means. More importantly, the thesis has demonstrated that this baseline data can be further modified and altered to create a series of legitimate alternative future scenarios which is anticipated to enable landscape architects to perform quantitative tests during the early stages of the design process.

5.5.2 Enabling Early Stage Landscape Performance Testing

Similar to how engineers are constantly trying to improve the implementation of building performance simulations in the early stages of design (Negendahl 2015), so too should landscape architects by pushing for early stage landscape performance testing. While it has been said that realistic representations of proposed scenarios in a point cloud format is at present a difficult task, the thesis finds that abstracted representations can still successfully interface with performative models. Here, simplified point clouds models embedded with custom metadata would serve as a suitable format to bridge between a simplified point cloud visual representation of the landscape and the qualitative mathematical models used to analyse it. Assuming that the technology and workflows are improved such that the iterative loop between designed scenarios and the testing results is tightened, more scenarios can be tested and more refinements can be made in a shorter period of time allowing for this transcend beyond simply a picturesque understanding of the scenarios into a decision support tool used in the early design stages of design.

Understandably we are still very far from being able to compile a complete set of parameters and analytical methods for measuring all aspects of landscape performance. Instead it would likely be that a pre-selected range of criteria be selected along with their corresponding tools and methods to measure and calculate their performance (Ellis et al. 2015). Also, while the demonstrated point cloud workflow might be able to adapt readily to performance models which rely more on mathematical equations, it remains to be seen how such a workflow can adapt to an equally important question of measuring intangible benefits, such as social and cultural benefits or even aesthetics. All these issues along with the technology to collect and work with point cloud data will surely improve over the coming years, but landscape architects need to begin to learn how to use them now while standards are being set and tools are being created in order to better inform manufacturers and developers of our specific requirements as landscape architects.

5.5.3 The Education of a Landscape Architect

With the growing need to provide credible evidence based support to evaluate the outcomes of designed scenarios, landscape architects need to develop the awareness, skills and resources to be able to design, evaluate and communicate results from landscape performance (Ndubisi et al. 2015). In unison, as we finally push to transit from our traditional two dimensional landscapes to completely three dimensional ones, we can no longer design our three dimensional world where access to the actual landscape is hidden behind two dimensional screens (Corner 1992b). The thesis has shown that point clouds and the tools and workflows associated with them can provide an avenue for a convergence of these ideas, providing a suitable three dimensional format from which designed scenarios can be tested. Yet as with all tools their effectiveness is largely dependent on the user's proficiency. The skill required to model and think in a 3D environment and the successful adoption of workflows in order to manipulate point cloud data are still very much user dependent and needs time to be inculcated. Hopefully by making the tools simple and accessible, this learning curve will be a gentle one and we should see more landscape architects taking up this approach.

Yet there is still a need to proceed with a degree of caution. Just as how generating perspectives might be seen as a purely picture making exercise, the technically sterile nature of collecting raw point cloud data might blind landscape architects from uncovering nuances in the landscape which are obscured from view when looking at the static scan of the landscape. With reality capture, gone is the laborious process of overlaying two dimensional topographical maps with a multitude of inputs from sketches, ground measurements, satellite imagery and publically available sources in order to produce the initial baseline data from which the work will hinge off. Yet this has always been a part of the process of grounding (the sorting and analysis of collected data) and finding (the discovery of an underlying strategy) (Girot 1999). Without walking the grounds, putting pen to paper, taking physical measurements, or experiencing the landscape as it progresses through time, could this process of grounding and finding be lost as we start relying on machines to obtain data for us. As such, while landscape architects and planners need to start exploring emerging technology and adopting this new 3 dimensional digital workflow, they need to do so with a highly critical eye to understand how they should be used and the benefits or pitfalls these technological advancements will bring to the table (Lovett et al. 2015).

5.5.4 Further Work Required to become Mainstream

In summary, the thesis finds that there is great potential in the use of point clouds in landscape architecture but there are still technical hurdles that need to be overcome and questions that need to be answered before becoming mainstream and adopted by landscape architects - both in practice and in academia. While the majority of the technical challenges lie outside of our discipline, the thesis identifies a list of possible areas in which more comprehensive studies can take place which would pave the way for point clouds becoming a permanent and adopted representative and performative format to turn to for landscape architects.

- *Comparing Point Clouds against other Traditional Methods* – While the thesis has briefly done so, more rigorous controlled experiments are required to investigate the fundamental changes in the design and communication process which occur when using point clouds instead of other traditional formats of landscape representation. Studies should uncover if the adopting of a point cloud workflow would yield richer designs or hinder them due to the difficulty in working with the data as well as the underlying changes which occur when doing so. Also, when communicating these designs in a point cloud environment, we need to understand if stakeholders are able to accept point clouds as a credible form of representation as opposed to traditional formats.
- *Deeper Integration With Neighbouring Disciplines* – It has shown that point clouds can serve as a neutral meeting point for different disciplines to converge upon. Further work needs to be done to explore the potential benefits of deeper integrations with neighbouring disciplines of GeoDesign, environmental and urban planning, urban ecology, architecture and even the social sciences. The thesis anticipates that furthering such multi-disciplinary studies can provide landscape architects with new opportunities to enrich their designs and subsequently obtain the buy in required from the various stakeholders.
- *Traversing Across Scales* - While point clouds can technically be used to represent anything from the entire river catchment down to a single tree if so desired, the scale at which the landscape architect desires to operate at has to match resolution of the original data capture. Stark differences between these scales exist; from data collection methods and processing to simulation and testing and finally to representation and communication. While the thesis mainly operated at the site and corridor scales, inter scalar interactions were very marginal if at all, perhaps because the gap between the scales was so great that it became impossible to quickly traverse across them. Studies need to be performed which correlate the intended scales of intervention with the appropriate means of data collection and uncover the differences in collection methods, workflows and tools required for this to happen.
- *Accuracy* – Different collection methods have varying degrees of accuracy. Even the use of UAVs requires accurate ground control points to be able to improve its accuracy. While designers often make do with the data they obtain, the hydraulic simulations performed in this thesis for example are much more sensitive to inaccuracies in the data. Landscape architects attempting to adopt these methods need to have an understanding of the degree of accuracy which is needed for their particular study and to apply the right data collection methods to meet this requirement.

- *Real World Demonstration* – Perhaps what is most lacking is a clear demonstration of the adopting of a point cloud workflow from start to end in a real world project. This would not only highlight the difficulties when point cloud representations need to be translated into working drawings but also provide for a serious platform to evaluate the representational tools and performance testing models to validate their effectiveness when built. The success or failure of such an endeavor would also pave the way for subsequent explorations and reflections on the use of point clouds in a real world project.

5.6 Outlook for the Ciliwung River

5.6.1 Point Clouds and the Ciliwung River

During the course of the project, a large proportion of time and energy was dedicated to trying to obtain usable point cloud data of the Ciliwung River at the various scales of intervention. As mentioned, publically available data was not only extremely scarce but was also deemed to be inaccurate for the resolution required by the thesis. While there was mention that an airborne LiDAR scan was performed over the river corridor, we had no privy to this data and were left to our own to establish the networks and partnerships which would ultimately make it possible - a process which took years to come to fruition. In comparison to this scant availability of data, the Philippine government actively rolled out a nationwide hazard assessment project in 2011 which comprised of a series of technological and management components to serve as disaster risk reduction; a detailed LiDAR scan of flood-prone and major river systems being one of the technologies adopted (Brower et al. 2014; Fernandez 2014). Within two years since its launch, 17 of the 18 critical basins have already been mapped with LiDAR, specifically for flood risk management (Serafica 2013).

This seemingly endless chase for data meant that valuable time was wasted which could have otherwise been used to test more realistic scenarios. As such, at this junction in time we can only speculate on how much further the thesis might have progressed if publically available point cloud data was available from the onset of the project, along with bathymetrical and ecological information. It is hoped that in future, accurate, up to date and readily available data – point cloud or otherwise – be made available to members of the public or at least to research institutes and NGOs working on areas in need of urgent interventions such as the Ciliwung River.

5.6.2 Is a "Green" Flood Mitigating Ciliwung River Corridor a Possibility

While the scientific knowledge generated of the entire Ciliwung River Corridor from the thesis and the team is still very much incomplete, the thesis has demonstrated that a hypothetical flood mitigation strategy based on calibrated use of landscape architectural ideas is a possibility. Unfortunately, though multiple workshops and seminars were carried out over the course of the project, this idea of "greening" the river corridor remains but an idea and it has become increasingly clear that the neither work done in this thesis nor the project has made any significant difference in either the condition of the Ciliwung River or the projected management path planned for it. This problem of translating scientific knowledge into the governance - caused by the misalignment of the drivers and objectives of the two - is one which is not specific to Indonesia (Wang et al. 2014). Further fueled by political sensitivity of the ongoing evictions and normalisation works, the perceived cycle of action and inaction of proposed interventions and the much more influential and powerful industrial actors holding billion dollar contracts, could be possible reasons why the suggestions by the team have largely gone unnoticed.

Indonesia itself also faces a multitude of other environmental issues on a much larger scale other than the floods such as the increasing loss of primary forests (Margono et al. 2014) and the ongoing forest fires (Ismail 2015) which make focusing on a single river seem extremely myopic. Unfortunately considering the historical trends, there is serious doubt on the sustainability of Jakarta's environmental fabric whose further deterioration will surely lead to serious economic, social and even political repercussions (Steinberg 2007).

While this inability to convince the local government is surely disheartening, perhaps the lesson that can be learnt is the reinforced need to back strong communication tools with credible scientific knowledge in order to obtain support and funding for such projects. It might already be "too little and too late" for the Ciliwung River, but the tools and workflows developed can be applied to other rivers and landscapes around the world, especially so in the megacities in Asia.

5.7 Final Conclusion

To conclude, the emergence of point clouds marks an exciting moment for landscape architecture. The thesis has demonstrated the definite possibility of adopting point clouds as a representative and performative format for landscape architecture, although there is still more ground to be covered to better understand the benefits and consequences of adopting such a workflow. From a technical point of view - while the hardware and software currently being developed are in a continual state of flux - landscape architects can and should already begin to experiment with this new format to push the discipline forward and embracing this new three dimensional digital medium. This will surely entail a fair amount of reinventions and adaptations to the established two dimensional workflows which need to be carefully weighed in. Perhaps only with a proper real world pilot project, backed by an accurate set of baseline data, showcasing the entire process from start to end with a list of measureable benefits obtained from the implementation, can we then prove that such an idea is not only feasible but highly beneficial on multiple fronts.

Chapter 6 – Appendix

6.1 Tool Details

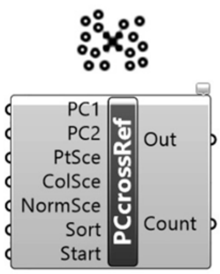
This portion of the appendix expands upon the details the tools developed in chapter 3.3. Here a more elaborate description is provided, with a list of inputs and outputs each tool requires as well as a description of the known issues identified with each tool. The tools are listed starting with the modification tools followed by the representational tools and finally the simulation support tools. Table 6.1 provides a description of the type of input or output the tool requires.

Table 6.1: List of the abbreviations used when describing the inputs and outputs required by the tools

Abbreviation	Description
BOL	*Boolean* – A switch with only a TRUE or FALSE option
BREP	*Boundary Representations* – A set or single Rhinceros brep object, typically in the form of solids or surfaces
COL	*Colour* – A set or single Rhinceros colour variable
CRV	*Curve* – A set or single Rhinceros curve object
FILE	*File Location & Name* – A text string which points to a location and file name on the hard drive
GUID	*Globally Unique Identifier* – A string of numbers and text which help to identify an object in Rhinoceros from another
INT	*Integer* – A set or single whole number / integer
MESH	*Mesh* – A set or single Rhinceros mesh object
NUM	*Floating Point Number* – A set or single floating point number (can include a decimal place)
PT3D	*Point in 3D Space* – A set or single Rhinceros curve object
TXT	*Text* – A text string or a single alphanumeric character
VEC	*Vector* – A set or single Rhinceros vector object

6.1.1 Modification Tools

Icon / Name	Description	Known Issues
PCcrossRef	Combines two point clouds together based on user defined parameters. The user selects from which point cloud to source the coordinate, colour and normal data from.	Works well only for gridded point clouds due to the need to sort the points to enable accurate cross referencing. Also only works for point clouds with the same number of points.



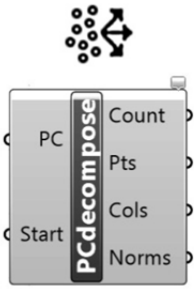
Inputs

PC1	*GUID* – First point cloud model
PC2	*GUID* – Second point cloud model
PtSce	*INT* – Which point cloud model to obtain point information from
ColSce	*INT* – Which point cloud model to obtain point information from
NormSce	*INT* – Which point cloud model to obtain point information from
Sort	*BOL* – Option to sort the points by cartisian coordinates
Start	*BOL* – Start the script

Outputs

Out	*GUID* – ID of output point cloud
Count	*INT* – Number of points in output point cloud

Icon / Name	Description	Known Issues
PCdecompose	Decomposes a point cloud object into its constituent parts and outputs lists for each component; point coordinates; colours; normals.	Works as described.



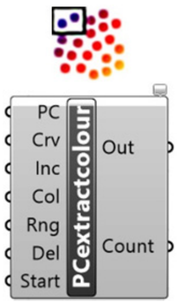
Inputs

PC	*GUID* – Point cloud model
Start	*BOL* – Start the script

Outputs

Count	*INT* – Number of points in output point cloud
Pts	*PT3D* – List of coordinates of the points within the point cloud
Cols	*COL* - List of colours of the points within the point cloud (if any)
Norms	*VEC* - List of normals of the points within the point cloud (if any)

Icon / Name	Description	Known Issues
PCextractColour	Extract points in a point cloud based on user selected colour. A curve is drawn in plan for which the points either within or outside of the curve are tested for. A user selected colour and range then allow the points close enough to the selected colour to be extracted. The result will be an extracted point cloud consisting of points which fall within the proximity of the chosen colour. Useful for extracting vegetation for example.	Trial and error is required to set the range value such that neither too little nor too many points are extracted, as a result the tool is difficult to be precise.



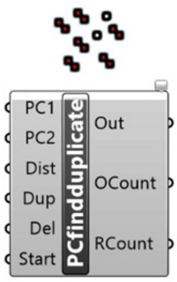
Inputs

PC	*GUID* – Point cloud model
Crv	*CRV* – A curve used to isolate the specific area of interest
Inc	*BOL* – If set to TRUE, points near to the selected colour will be extracted
Col	*COL* – An input colour in RGB from which to compare against
Rng	*INT* – A range from 0 to 255 indicating how far away from the selected colour to include
Del	*BOOL* – If set to TRUE, the original point cloud will be deleted
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point cloud
Count	*INT* – Number of points in output point cloud

Icon / Name	Description	Known Issues
PCfindDuplicate	Finds duplicate points between two point clouds based on a user defined distance. The coordinates of the points within two point clouds are checked against the user defined distance variable and points falling within this distance are extracted or removed.	Script is very slow when attempting to cross referencing two large point clouds. More optimisation is needed.



Inputs

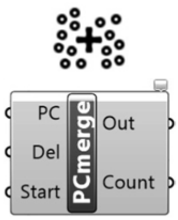
PC1	*GUID* – First point cloud model
PC2	*GUID* – Second point cloud model
Dist	*NUM* – A user set distance from which a point is considered a duplicate
Dup	*BOOL* – If set to TRUE, the duplicate point will be extracted

Outputs

Out	*GUID* – ID of output point cloud
OCount	*INT* – Number of points in the original point cloud
RCount	*INT* – Number of points in the resultant point cloud

Del	*BOOL* – If set to TRUE, the original point cloud will be deleted
Start	*BOOL* - Starts the script

Icon / Name	Description	Known Issues
PCmerge	Merges multiple point clouds together.	Works as described.



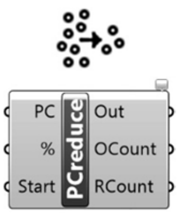
Inputs

PC	*GUID* – List of point cloud models to merge
Del	*BOOL* – If set to TRUE, the original point clouds will be deleted
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point cloud
Count	*INT* – Number of points in output point cloud

Icon / Name	Description	Known Issues
PCreduce	Reduces the number of points in a point cloud object by setting a target percentage to randomly remove points within the point cloud. Useful for lowering computational or viewport overheads.	Works as described.



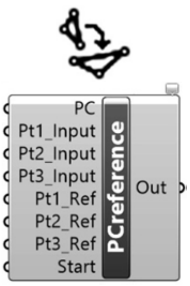
Inputs

PC	*GUID* – Point cloud model
%	*INT* – Target percentage of the number of points in the original point cloud to reduce to
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point cloud
OCount	*INT* – Number of points in the original point cloud
RCount	*INT* – Number of points in the resultant point cloud

Icon / Name	Description	Known Issues
PCreference	Transforms a point cloud to fit into a user defined location. 3 pairs of user defined points are set to translate, rotate and scale a point cloud from its original location to a targeted referenced location.	Transformations are very fast but are completely dependent on the user finding the best corresponding points for the transformation to occur.



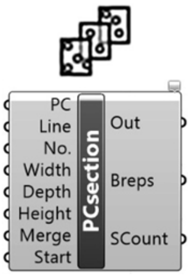
Inputs

PC	*GUID* – Point cloud model
Pt1_Input	*PT3D* – An input coordinate for the first point in the point cloud model
Pt2_Input	*PT3D* – An input coordinate for the second point in the point cloud model
Pt3_Input	*PT3D* – An input coordinate for the third point in the point cloud model
Pt1_Ref	*PT3D* – A reference coordinate to translate the first input point to
Pt2_Ref	*PT3D* – A reference coordinate to translate the second input point to
Pt3_Ref	*PT3D* – A reference coordinate to translate the third input point to
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point cloud

Icon / Name	Description	Known Issues
PCsection	Creates sectional samples from a point cloud by using a curve input and temporary rectangular blocks to extract points which fall within these blocks. Useful for extracting sections along rivers and roads.	Does not create a truly orthographic section, instead just a longitudinal sampling of the input point cloud.



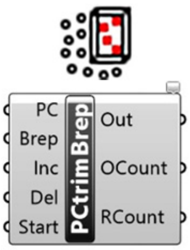
Inputs

PC	*GUID* – Point cloud model
Line	*CRV* – A curve which indicates the spine of the extracted sections
No.	*INT* – Number of evenly spaced sections along the curve to be extracted
Width	*NUM* – Width of section to be extracted
Depth	*NUM* – Depth of section to be extracted
Height	*NUM* – Height of section to be extracted
Merge	*BOOL* – If set to TRUE, extracted sections will be merged together
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point cloud
Breps	*BREPS* – List of rectangular Breps used to extract the sections, when previewed will provide a visual indication of the size of the sections to be extracted
SCount	*INT* – Number of points in the extracted point cloud sections

Icon / Name	Description	Known Issues
PCtrimBrep	Trims a point cloud using a single brep or a set of breps to separate parts of a point cloud. Useful for separating identified objects in a point cloud model, e.g. a tree or a bridge.	Works as described.



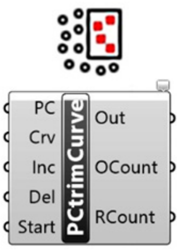
Inputs

PC	*GUID* – Point cloud model
Brep	*BREP* – List of closed rectangular Breps to be used to test for inclusion.
Inc	*BOOL* – If set to TRUE, the points inside the Breps will be extracted
Del	*BOOL* – If set to TRUE, the original point clouds will be deleted
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point cloud
OCount	*INT* – Number of points in the original point cloud
RCount	*INT* – Number of points in the resultant point cloud

Icon / Name	Description	Known Issues
PCtrimCurve	Similar to PCtrimBrep but uses curves instead. Useful for separating identified areas in a point cloud model, e.g. a patch of vegetation.	Works as described.



Inputs

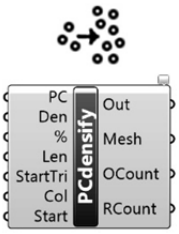
PC	*GUID* – Point cloud model
Crv	*CRV* – List of closed curves to be used to test for inclusion.
Inc	*BOOL* – If set to TRUE, the points inside the curves will be extracted
Del	*BOOL* – If set to TRUE, the original point clouds will be deleted
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point cloud
OCount	*INT* – Number of points in the original point cloud
RCount	*INT* – Number of points in the resultant point cloud

6.1.2 Representation Tools

Icon / Name	Description	Known Issues
PCdensify	Densifies a point cloud through simple extrapolation. Additional points are added in between the existing points in the point cloud model. The user can define the density, simplification and maximum length in order to obtain a densification that is visually acceptable.	Tool is is neither accurate nor fast due to the simplistic algorithm behind it.



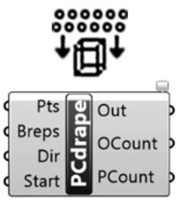
Inputs

PC	*GUID* – Point cloud model
Den	*INT* – Number of times to densify by, e.g. 2 doubles the number of points
%	*INT* – Percentage of original points to use in densification process, high values lead to more accuracy but longer processing times
Len	*NUM* – Maximum length between points to add additional points, set to a value which is representative of the average distance between points in the point cloud
StartTri	*BOOL* – Starts the triangulation portion of the script
Col	*BOOL* – If set to TRUE, the script will attempt to sample the colour from the original point cloud
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point cloud
Mesh	*MESH* – If previewed, will show a mesh indicating the results of the triangulation process.
OCount	*INT* – Number of points in the original point cloud
RCount	*INT* – Number of points in the resultant point cloud

Icon / Name	Description	Known Issues
Pcdrape	A user defined list of points are projected onto a series of breps populating the surface with points. Useful for converting user modelled surfaces such as a new topography into a point cloud model.	Very slow algorithm due to the need to test for intersections for each and every point.



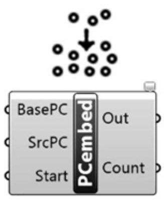
Inputs

Pts	*PT3D* – A list of points to drape onto the underlying breps
Breps	*BREP* – List of closed breps to drape the points onto
Dir	*VEC* – If set to TRUE, the points inside the curves will be extracted
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point cloud
OCount	*INT* – Number of points at the start of the drape process
PCount	*INT* – Number of points in the resultant point cloud

Icon / Name	Description	Known Issues
PCembed	Embeds a gridded source point cloud into another base point cloud, replacing original underlying data The points in the source point cloud will replace the underlying base point cloud where they coincide in X & Y coordinates.	Can only be used on gridded point clouds where the X and Y coordinates exactly coincide with each other.



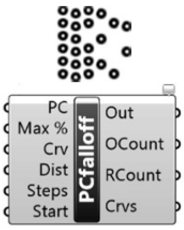
Inputs

BasePC	*GUID* – Point cloud to embed into
SrcPC	*GUID* – Point cloud to embed from
Start	*BOOL* - Starts the script

Outputs

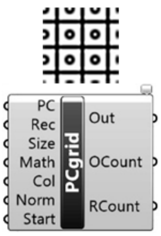
Out	*GUID* – ID of output point cloud
OCount	*INT* – Number of points in the original point cloud

Icon / Name	Description	Known Issues
PCfalloff	Creates a gradiented reduction in points from a source closed curve. The user provides a reduction amount, falloff distance and number of steps to create a smooth reduction outside of the user defined curve. Was created to reduce abruptness of the jarring boundaries where the collected point cloud models end.	While the algorithm works, it was hardly ever used.



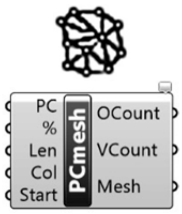
Inputs		Outputs	
PC	*GUID* – Point cloud model	Out	*GUID* – ID of output point cloud
Max%	*INT* – Maximum percentage of original points to retain	OCount	*INT* – Number of points in the original point cloud
Crv	*CRV* – Points falling within the closed curve will remain untouched	RCount	*INT* – Number of points in the resultant point cloud
Dist	*NUM* – Distance from input curve after which maximum reduction is used	Crvs	If previewed will show the steps used in the fall off process
Steps	*INT* – Number of steps used to calculate the fall off, the higher the number the smoother the transition but the slower the speed		
Start	*BOOL* - Starts the script		

Icon / Name	Description	Known Issues
PCgrid	Simplifies a point cloud into a square grid. A boundary curve, grid size and a choice between choosing the highest, lowest or average height within the points of a grid cell can be defined. In addition the colour and normal of the point closest to the centre of each grid cell can be extracted as well.	Occasionally some points in the output grid are missing, this might be due to a bug in the parallised code.



Inputs		Outputs	
PC	*GUID* – Point cloud model	Out	*GUID* – ID of output point cloud
Rec	*CRV* – Closed rectangular curve within which the points will be gridded.	OCount	*INT* – Number of points in the original point cloud
Size	*INT* – Size of grid cells	RCount	*INT* – Number of points in the resultant point cloud
Math	*INT* – Used to determine if the minimum, maximum or mean height is used in the output point (0 = max, 1 = min, 2 = mean)		
Col	*BOOL* – If set to TRUE, colour information will be extracted based on the point nearest to the center of the cell		
Norm	*BOOL* – If set to TRUE, normal information will be extracted based on the point nearest to the center of the cell		
Start	*BOOL* - Starts the script		

Icon / Name	Description	Known Issues
PCmesh	Converts a point cloud to a mesh using Delaunay triangulation. Works best for gridded point clouds and is useful when generating a mesh to be milled with a CNC machine. A simplification factor can be used to allow faster calculations and colour information can be transferred from the point cloud to the mesh.	Relies on the internal Delaunay triangulation algorithm, as such is only suitable for simple gridded models. Colour transfer does not work well.



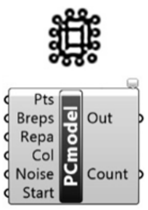
Inputs

PC	*GUID* – Point cloud model
%	*INT* – Percentage of original points to use in triangulation process, high values lead to more accuracy but longer processing times
Len	*NUM* – Maximum length between points in the resultant mesh, set to a value which is representative of the average distance between points in the point cloud
Col	*BOOL* – If set to TRUE, colour information will be extracted based on the point nearest to the center of the cell
Start	*BOOL* - Starts the script

Outputs

OCount	*INT* – Number of points in the original point cloud
VCount	*INT* – Number of points in the resultant point cloud
Mesh	*MESH* – If previewed, will show a mesh indicating the results of the triangulation process.

Icon / Name	Description	Known Issues
PCmodel	Creates a point cloud from faces of Breps. Useful for generating new point clouds out of surface geometry, such as a new river bathymetry or buildings. A desired total number of points and a colour can be set and the points are distributed as evenly as possible across all the faces of the selected Breps.	Point spacing cannot be defined, as such it is difficult to evenly spread the points across the surfaces.



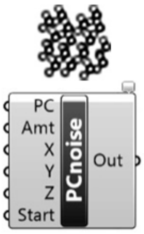
Inputs

Pts	*INT* – Number of points to populate the Breps with
Breps	*BREPS* – List of Breps from which their surfaces will be used to distribute the points onto
Repa	*BOOL* – If set to TRUE, all faces will be reparameterised. Do this if there are issues with the evenness of points distributed over the faces of breps
Col	*COL* – User defined colour of the output point cloud model
Noise	*INT* – Amount of noise to add to the colour of the points
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point cloud
Count	*INT* – Number of points in output point cloud

Icon / Name	Description	Known Issues
PCnoise	Adds random noise to the coordinates of a point cloud object. Useful to break up the otherwise rigid appearance of created point cloud models using PCdrape or PCmodel. A maximum displacement amount and the axis of displacment can be adjusted by the user.	Works as described.



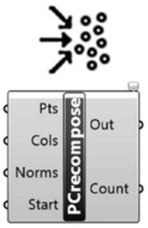
Inputs

PC	*GUID* – Point cloud model
Amt	*NUM* – Maximum displacement in world units
X	*BOOL* – If set to TRUE, noise displacement will occur in the X axis
Y	*BOOL* – If set to TRUE, noise displacement will occur in the Y axis
Z	*BOOL* – If set to TRUE, noise displacement will occur in the Z axis
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point cloud

Icon / Name	Description	Known Issues
PCrecompose	Recomposes a list of points, colours and normals back into a point cloud (colours and normals are optional). Used in conjunction with PCdecompose to replace the values of the original point cloud, e.g. replacing RGB data with a shaded elevational gradient.	If colours and/or normals are included, they need to correspond to the list of points directly in both the number of points as well as the order in which they are listed.



Inputs

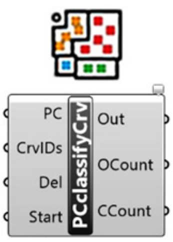
Pts	*PT3D* – List of input points
Cols	*COL* – List of input colours
Norms	*VEC* – List of input normals
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point cloud
Count	*INT* – Number of points in output point cloud

6.1.3 Simulation Support Tools

Icon / Name	Description	Known Issues
PCclassifyCrv	Seperates a point cloud into different layers based on a series of closed curves. The user draws classification boundaries in plan, one layer for each desired class, and the points within these curves will be extracted and moved to the respective layers. Useful for separating the point cloud model by identified area, e.g. vegetated areas or urban areas.	The tool works but the drawing of the curves is a hassle as there is a need to ensure that the vertices of the curves coincide perfectly.



Inputs

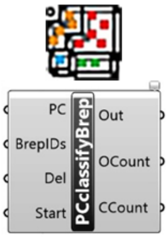
PC	*GUID* – Point cloud model
CrvIDs	*CRV* – List of closed curves on different layers corresponding to the required classification categories
Del	*BOOL* – If set to TRUE, the original point clouds will be deleted
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point clouds
OCount	*INT* – Number of points in the original point cloud
CCount	*INT* – Number of points in the classified point clouds

Icon / Name	Description	Known Issues

PCclassifyBrep



Description: Similar to PcclassifyCrv but uses a a series of closed Breps instead of curves. The user draws Breps, one layer for each desired class, and the points within these breps will be extracted and moved to the respective layers. Useful for separating the point cloud model by identified volumes, e.g. Isolating trees or buildings

Known Issues: The tool works but the drawing of the breps is a hassle as there is a need to ensure that the vertices of the breps coincide perfectly.

Inputs

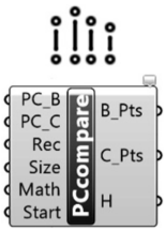
PC	*GUID* – Point cloud model
BrepIDs	*BREP* – List of closed breps on different layers corresponding to the required classification categories
Del	*BOOL* – If set to TRUE, the original point clouds will be deleted
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point clouds
OCount	*INT* – Number of points in the original point cloud
CCount	*INT* – Number of points in the resultant point clouds

Icon / Name	Description	Known Issues

PCcompare



Description: Simplifies 2 point clouds into grids & measures the differences in height at grid points. Useful for finding out how much earth was moved in a designed scenario or the difference in height between the tree canopy and the ground. Two point clouds, a base and one for comparison are gridded similar to PCgrid after which the difference is height is measured at the grid points.

Known Issues: The tool works but can be slow depending on the number of points to calculate.

Inputs

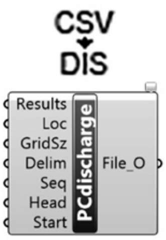
PC_B	*GUID* – Base Point cloud model (typically represents the ground plane)
PC_C	*GUID* – Point cloud model to compare against (typically represents the surface plane, tree and roof tops)
Rec	*CRV* – Closed rectangular curve within which the points will be gridded.
Size	*INT* – Size of grid cells
Math	*INT* – Used to determine if the minimum, maximum or mean height is used in the output point (0 = max, 1 = min, 2 = mean)
Start	*BOOL* - Starts the script

Outputs

B_Pts	*PT3D* – List of points which represent the gridded base point cloud model
C_Pts	*PT3D* – List of points which represent the gridded compared point cloud model
H	*NUM* – List containing the difference in height between the gridded base and compared point cloud models

Icon / Name	Description	Known Issues

PCdischarge



Description: Calculates discharge at a particular location from 2dMb results and writes the results into a file. Useful for isolating a particular point along the course of the river for analysis. A closed curve is draw in plan within which the total discharge will be calculated based on the 2dMb results file.

Known Issues: Discharge is dependent on where and how big the curve is drawn. Care has to be taken not to misinterpret the results.

Inputs

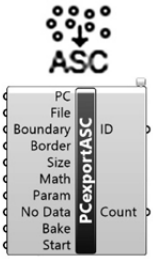
Results	*FILE* – Location of files containing 2dMb results
Loc	*CRV* – Closed curve from which to calculate the discharge results from

Outputs

File_O	*FILE* – Location of output file with discharge results

GridSz	*INT* – Size of grid cells
Delim	*TXT* – Deliminator used in the results file (typically either a space or a comma)
Seq	*TXT* – Sequence of fields in results file, seperated by a comma (e.g. x,y,z,s,u,x,q where s = skip)
Head	*INT* – Number of lines in the header of the file before the actual data starts
Start	*BOOL* - Starts the script

Icon / Name	Description	Known Issues
PCexportASC	Exports a point cloud as an ASCII grid. Useful to export the point cloud into a format that can be used in ArcGIS or FRAGSTATS. The gridding is based on PCgrid with the additional option of exporting a value other than the Z coordinate. E.g., exporting the R channel as an analog for classification information. In addition, a boundary and border curve can be included specifically for particular FRAGSTATS analysis.	ASC files allow only for the XY coordinates and one other value to be exported.



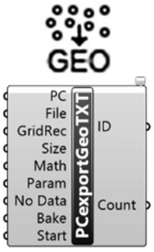
Inputs

PC	*GUID* – Point cloud model
File	*FILE* – Desired location and name of output ASC file
Boundary	*CRV* – Closed curve used to indicate the boundary of the point cloud to be exported
Border	*CRV* – Closed curve used to indicate the border of the point cloud to be exported (Used in certain FRAGSTATS calculations)
Size	*INT* – Size of grid cells
Math	*INT* – Used to determine if the minimum, maximum or mean height is used in the output point (0 = max, 1 = min, 2 = mean)
Param	*TXT* – Additional parameter to be exported into ASC file. (select one from xyzrgbuvw, e.g. r for the red channel)
No Data	*INT* – Value to be used in ASC file where no data is found
Bake	*BOOL* – If set to TRUE, resultant gridded point cloud will be output into the Rhino viewport as well.
Start	*BOOL* - Starts the script

Outputs

ID	*GUID* – ID of output point cloud
Count	*INT* – Number of points in the gridded point cloud

Icon / Name	Description	Known Issues
PCexportGEO	Exports apoint cloud as GeoTXT grid for 2dMb. Specifically written to integrate with 2dMb flood simulations carried out with the help of the engineers in the team. Essentially similar to PCexportASC but the output file in this case is specifically written in a format to directly be used in 2dMb.	The GeoTXT file format is not a universal format and coordination with the engineers of the team is necessary to ensure that the file formating is in line with their requirements.



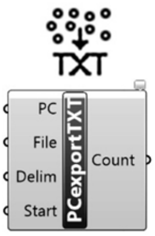
Inputs

PC	*GUID* – Point cloud model
File	*FILE* – Desired location and name of output ASC file
GridRec	*CRV* – Closed curve used to indicate the extent of the point cloud to be exported
Size	*INT* – Size of grid cells
Math	*INT* – Used to determine if the minimum, maximum or mean height is used in the output point (0 = max, 1 = min, 2 = mean)
Param	*TXT* – Additional parameter to be exported into ASC file. (select one from xyzrgbuvw, typically z is used here for the flood simulations)
No Data	*INT* – Value to be used in ASC file where no data is found
Bake	*BOOL* – If set to TRUE, resultant gridded point cloud will be output into the Rhino viewport as well.
Start	*BOOL* - Starts the script

Outputs

ID	*GUID* – ID of output point cloud
Count	*INT* – Number of points in the gridded point cloud

Icon / Name	Description	Known Issues
PCexportTXT	Exports a point cloud as human readable text file. The user defines the deliminator and file location, after which the tool outputs each point in the point cloud model as a line in the text file with its attributes seperated by the defined deliminator.	The TXT file format while convenient is probably one of the most primitive formats to use without any compression or indexing.



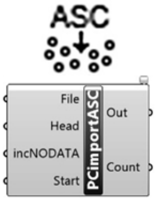
Inputs

PC	*GUID* – Point cloud model
File	*FILE* – Desired location and name of output text file
Delim	*TXT* – Deliminator used in the results file (typically either a space or a comma)
Start	*BOOL* - Starts the script

Outputs

Count	*INT* – Number of points in the point cloud

Icon / Name	Description	Known Issues
PCimportASC	Imports a point cloud from an ASC file. Useful for importing files exported by ArcGIS for example. The user also has a choice of whether or not to include points which have been identified as having no data.	The number of lines in the header needs to be manually keyed in and only human readable ASC files (non-binary) can be read.



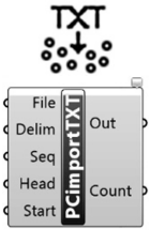
Inputs

File	*FILE* –Location and name of input ASC file
Head	*INT* – Number of lines in the header of the file before the actual data starts
incNODATA	*BOOL* – If set to TRUE, no data values will be imported as well
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point cloud
Count	*INT* – Number of points in output point cloud

Icon / Name	Description	Known Issues
PCimportTXT	Imports a point cloud from a text file. The simplistic but convenient TXT file is useful for transferring data amongst colleagues each using a different software package. The user specifies the deliminator used in the TXT file (usually a comma or a space) as well as the order of data in the text file.	The number of lines in the header needs to be manually keyed in and only human readable TXT files (non-binary) can be used.



Inputs

File	*FILE* –Location and name of input text file
Delim	*TXT* – Deliminator used in the results file (typically either a space or a comma)
Seq	*TXT* – Sequence of fields in results file, seperated by a comma (e.g. x,y,z,s,r,g,b,u,v,w where s = skip)
Head	*INT* – Number of lines in the header of the file before the actual data starts
Start	*BOOL* - Starts the script

Outputs

Out	*GUID* – ID of output point cloud
Count	*INT* – Number of points in output point cloud

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