Representing Dynamic Landscapes: Temporal Point Cloud Visualisation Applications in Complex Ecologies: The Case Study of the 2020 Rosedale Fires

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Abstract: The representation of complex landscape scenarios often requires the simplification of spatial datasets, especially in dynamic landscape contexts. This research documents a method for the implementation of multiple coincident point clouds into a temporal model that maps the transformation of the site over time, demonstrating clear contributions to areas of site response, design and management. The point cloud datasets consisted of UAV photogrammetry collected after the fire event, and municipal ALS data predating the fires. The research is focused on the specific interface of fire-affected forest and inhabited areas in the coastal community of Rosedale, NSW Australia, and demonstrates how point cloud technologies can be applied in hybrid temporal models in the spatial visualisation, comprehension, and reconstruction of these environments.

Keywords: UAV photogrammetry, point cloud modelling, fire impact visualization, temporal point cloud layering, dynamic landscape modeling, landscape analysis, landscape restoration

1 Introduction

This research demonstrates the implications for dynamic landscape comprehension and design through the combination of spatial datasets, in particular the use of hybrid point clouds. In landscape environments that are subject to increasing extremes of weather and climate performance and unpredictable site response, this research enables the construction and visualisation of these complex local site realities. Through the detailed combination of a temporal model that maps the transformation of the site over time, clear contributions to the planning of site response, design and management can be demonstrated.

The research case study investigates a specific fire-affected site and applies varied point cloud technologies in the spatial visualisation, comprehension, and reconstruction of these environments. The research is focused on the specific interface of fire-affected forest and inhabited interfaces in a post-fire context in Rosedale, NSW Australia, an ongoing area of research (MELSOM 2020). These specific investigations shall be shown to demonstrate the practical potential of such techniques for site-specific applications, contribution to the documentation of the cause, impact and potential response to a specific fire event, and the associated implications for landscape management and design.

In landscape environments that are subject to increasing extremes of weather and climate performance and unpredictable site response, this research enables the construction and visualisation of these complex local site realities. The usefulness of combining point cloud datasets from various sources, including UAV photogrammetry and LIDAR has been demonstrated as an established technique in forestry (JAYATHUNG 2018, FILIPPELLI 2019) and even in certain fire-affected landscapes (VIEDMA 2020), principally in the generation of GIS spatial datasets and other forms of raw data. This research demonstrates a method for dynamic

Journal of Digital Landscape Architecture, 7-2022, pp. 282-290. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-724-3, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537724027.

landscape comprehension and design through the combination of point cloud datasets, and the subsequent remote sensing data interpolation, and visualisation.

Through the combination of spatial datasets, in particular the use of hybrid point clouds, this process demonstrates the implications for dynamic landscape comprehension and design, from specialists to stakeholders. In landscape environments that are subject to increasing extremes of weather and climate performance and unpredictable and complex site response, this research enables the construction and visualisation of these complex local site realities. Through the detailed combination of a temporal model that maps the transformation of the site over time, clear contributions to the planning of site response, design and management can be demonstrated.

While simple cloud to cloud comparisons are commonplace, the superimposition of potential landscape change models in a detailed spatial form, whether built, vegetal or modelled environmental response hold clear potential for landscape architecture design, and response to evolving landscape challenges.

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The term “dynamic” also refers to the ability to interpolate between cloud states, and work with comparative environmental models (non-point cloud data). A key example is the ability in this case to demonstrate initial epicormic regrowth and stress (fire) response, and longer-term re-establishment of canopy.

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2 Methodology

In contemporary forestry management, the use of point cloud techniques is widespread in the management, analysis and visualisation of forest systems (HOLLAUS 2015). Analogous techniques and methods have been published by the author in various landscape applications (MELSOM 2018). Such forestry point cloud analysis techniques, including the depiction of species, densities, canopy extent have been analysed as metrics fundamental to fire prediction, such as fuel loads, intensity predictions and susceptibility to fire, however they are primarily used in forward-looking large-scale risk mitigation and regional extrapolation (FILIPPELLI 2019). The large-scale challenge of representing fire risk, management, and response is well documented and has been met with various computational and visualisation tools (MILLER 2015). Such simulation modelling is often however limited to a 2D+ spatial model, due to the complexity of input data required and the unpredictable nature of fire behaviour at the detailed scale (HILTON 2020).

Fig. 1: Example of UAV photogrammetry source imagery showing fire impact interface

It is through a combination of these methods, and landscape architecture spatial modelling softwares that site data acquisition, interpretation, analysis and visualisation may take place.

2.1 Site Data Acquisition and Synthesis

The research case study is located in North Rosedale, New South Wales, a coastal area thoroughly impacted by the 2019-20 bushfires. The specific site covers the interface between an area both affected and untouched by direct fire damage, which a broader research project was developed with the community of Rosedale and the local municipality (ALLAN 2020). The subsequent need for landscape strategies for recovery, repair, and the development of new protocols of maintenance and care is the subject of a border research project; this research focuses on the methods of representing these complex fire-affected spaces.

The research is based on data sourced from various sources including various pre-fire government sources, such as high-altitude regional government territorial aerial LIDAR data, and municipal low-altitude site-specific LIDAR scans. The post-fire data consisted of a detailed UAV based photogrammetric scan of the site, which was collected by the author on site (Figure 1). The site had largely remained unchanged due to the severity of the fires, and the slow process of rebuilding, yet some post-fire epicormic response was visible. This burnt/unburnt interface also provided excellent comparative dataset controls for the site data from the pre-fire period. The lack of canopy in the fire-affected areas leads to an uncharacteristically accurate photogrammetry dataset of the landscape in these areas, akin to open forested point cloud dataset results documented in other research (FRITZ 2013) and lending itself well to combine with the existing point cloud datasets.

A key research step is in the temporal overlay of point clouds scanned before and after the fire event. Cloud to cloud comparison is a fundamental and well-documented technique of landscape analysis, rendering visible the difference between datasets, whether physical or in values. These techniques were applied to point distance as well as data values, allowing additional previously interpolated aspects such as NIR, the Fire Extent and Severity Mapping (FESM), species, stand density, and planning zoning or restrictions.

Lack of local information, especially in fire affected areas, required the analysis of past datasets. In this specific example this allows the reconstruction of Eucalypt and Acacia forest mix, and simulation of canopy form and density, a key determinant in this coastal landscape for fire spread and impact.

2.2 Cloud Interpolation of External Data Sources

Interpolation took place in two forms; interpolation or transfer of characteristics across datasets to enrich existing data, and in the ability to generate "in-between" models of detailed fragments, to imply regrowth, understand the extent of site recovery, and also generate alternate future site configurations.

Table 1: Table of research-specific implementation of point clouds and terrestrial data for interpolation and data sources, organised by date of procurement

Data Type	Data Source	Resolution	Details	Capture Date	Source
ALS Point cloud	LADS HD	2m /pt	Point cloud: RGB (Phase One), Classified	07.08.2018/ 14.06.2019	FUGRO/ NSW Govt.
ALS Point cloud	RIEGL VQ-820-G	0.2-1m /pt (0.5m ave.)	Point cloud: Intensity, Classified	07.08.2018/ 14.06.2019	FUGRO/ NSW Govt.
Aerial RGB Imagery	Phase One IXU-RS-1000	0.1m /pix 100MP	Aerial Mosaic RGB data, synced to LADS HD	07.08.2018/ 14.06.2019	FUGRO/ NSW Govt.
Satellite NIR Imagery	SPOT 6/7	1-1.5m /pix	Satellite Mosaic NIR data	09.2019/ 04.2020	Geospatial Intelligence
Initial Rosedale fire event 31.12.2019-02.01.2020*					
UAV RGB Photogrammetry	MAVIC 2 Pro 20MP	0.1-0.5m /pt	Point cloud: RGB, Classified	17.03.2020	Melsom UTS
UAV NDVI Photogrammetry	MAVIC Pro Agrocam NDVI	0.5m /pix	Raster	18.03.2020	Melsom UTS
Satellite NIR Imagery	SPOT 6/7	1-1.5m /pix	Satellite Mosaic NIR data	4.2020	Geospatial Intelligence

The technical implementation of these aspects meant that the benefits of the specific point cloud datatypes could be exploited, and limits of the various interpolated datasets addressed, notably limited resolution and lack of spatial definition. As noted (Table 1) the varied sources and dates of data procurement in relation to the fire and landscape recovery and response are critical to the understanding of the data and provide key additional data that is transferred into the point cloud database information for later retrieval, as the layers are assembled.

As previously mentioned the data mapping of tree species and canopy measurement is of key importance to understand both past and future fire resilience. The combination of reflectance and RGB point values of previous canopy stands with local site observations and extrapolation of species allowed visually subtle differences of species within the forest mix to be determined. A further example is the embedding of ownership and custodianship data into the spatial point cloud datasets, especially vegetation. The resulting mappings demonstrate the responsibility of local government, organizations and individual landholders for direct risk analysis and opportunities or requirements for collaboration and partnership that otherwise remain obscure.

The photogrammetric point cloud dataset, both the most dense and descriptive of the fire affected areas, formed a key recipient of interpolated data, facilitating detailed interaction of causal, direct and reconstructive data layers and information, in preparation for the phases of visualisation and analysis (Figure 2). The interpolated datasets were rigorously documented, facilitated by the ability to encode point cloud data points with multiple scalar data forms, or created supporting GIS data layers in which other data formats and textual information could be readily stored and retrieved.

Fig. 2: Filtered ALS point cloud object data (LADS HD, June 2019) and the UAV campaign photogrammetry data (March 2020)

2.3 Visualisation Methods and Comparative Models

It is in the visualisation of these datasets and models and their comparative application that the potential of these techniques for such dynamic processes is revealed. Comparative layering of datasets requires visualisation approaches that reveal difference, contrast and change, rather than obscure these elements. The transparent nature of point cloud rendering becomes a key aspect in the ability to measure and communicate landscape change and represent both destructive and constructive potential.

These processes took place in three key steps: overlay (contrast); measurement (difference); and projection (potential). In the case of the fire-affected landscapes of Rosedale, several key examples can be drawn to demonstrate these steps.

Overlay of the interpolated point clouds with planning regulation models formed a crucial aspect of the site investigations, due to their logics of spatial relationships focused on built structures, relying on distance, intervening slope, the requirements of which are determined by the type of vegetation, height, and density. Such models are typically planned and applied nevertheless using non-spatial models, greatly reducing the potential for compromise, and often resulting in the clearing of large areas of vegetation as a direct result of each major fire event.

Measurement refers to the various established modes of determining exact comparative change, as well as non-spatial impacts. The former is demonstrated through the direct measurement between clouds, resulting in this case study as distance, physical absence and growth, as well as volume of vegetative material both living and litter. The resulting characteristics such as biomass, fuel, and erasure can be re-interpolated into the cloud data in a legible manner. Less spatial measurement such as vegetative health and stress, and shifts in shade, wind shadow, and other environmental impacts were also re-encoded into the clouds.

Projection refers to the potential to re-present the landscape context and its inherent layers and as a model within which planning can take place. The representation of physically abstract forest characteristics such as stand density, firebreak impact, and evacuation paths are key research examples (Figure 3). The incorporation of multiple iterations of design proposals is also important in such a scenario, as the process of recovery is often piecemeal and fragmented and requires a flexible trajectory.

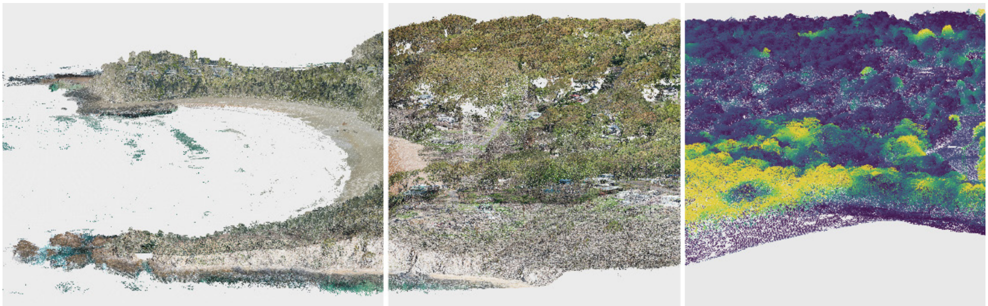

Fig. 3: Combined spatial models demonstrating dynamics of spatial environmental (l), fire impact photogrammetry with potential fire responses (m) and example analysis layer of crown loss (r) as co-incident navigable spatial design model.

It is in discussion with local residents that the desire for shifts in fire planning paradigms was demanded, in contexts in which shifting climatic and economic pressures on the landscape are continually transforming the impact of fire other phenomena, to which traditional responses are no longer adequate. Many of these results, community exchange and impact have been documented as part of an exhibit at the Venice Architecture Biennale 2021 (ALLAN 2021).

3 Discussion

This research combined various types of point cloud datasets, privately sourced and generated on-site, with GIS and spatial analysis data to create spatial visualisations, with results that may be standardized, a technique that can be reproduced within the site, enabling comparative analysis. The application to analogous sites, both fire-affected and unaffected enable multiple locations and hybrid temporal visualisations to be simultaneously visualised and characterized, in scaled, measurable models.

The spatial nature of the representation techniques allows for dynamic representation techniques, such as animation, AR, and transitional models in real-time, with no additional manipulation required. This facilitated complex scenarios to be understood, both by specialists and stakeholders. As in many such research modes, it is not the minute individual steps that represent novel areas of potential, but their combination and resulting effect. In this case the approach has been applied in site analysis, local government collaborative research, graduate landscape architecture teaching syllabus, and is currently begin adapted to form the framework for future fire-affected landscape response in further coastal areas of Australia in funded multidisciplinary collaboration.

Due to the specific nature of the case studies, certain limitations were encountered, such as the inaccessibility of the sites during critical timeframes of transformation. Restrictions on drone usage around fire-affected sites are widespread throughout the world. The combination with other forms of site documentation and communication and cartography are essential to ensure that the potential for communication and transformation is achieved; this technique does not replace traditional planning techniques, however, has proved to provide powerful tools for such complex and quickly evolving scenarios.

4 Conclusion and Outlook

The research demonstrates the complex level of information that can be represented with point cloud models, in a standardised, replicable, and consistent manner, while maintaining links to the source analysis data, and the ability to supplement the spatial models over time with additional metrics and interfaces. While the case study focuses on fire, other scenarios of dynamic landscape characteristics can be clearly addressed using analogous techniques of surveying, superimposition, interpolation and representation. Limits to the techniques lie in the accessibility of the required data, the reliance on the ALS source data for fidelity, density and classification, and access to the site for UAV photogrammetry, often restricted around such sites. The level of abstraction of the models does not lend their use to general public information, favouring specialist discussion and direct visualisation as a spatial modeling tool.

The conceptual model as forensic "reconstructions" of the site is useful in describing the impact and potential areas of application of the research. It is relevant in several typical phases of fire response and recovery in an inhabited environment, often not represented in a site-specific spatial manner. At the territorial scale, it describes the requirement to model the terrestrial conditions, the environmental influences including wind, historical rainfall, and local factors surrounding the site; it describes the local forensic reassembly of the affected sites and mitigating conditions, as well as the responses taken by local individuals; in the planning for rebuilding and re-establishment of ecologies; and not least of which the development of local protocols of care and planning for future fire events. In the case of fires in the extreme nature of the Sydney 2019-20 fires, it also leads to a further revision of laws and regulations regarding the process of rebuilding, (SA 2020, building code) directly affecting the future configuration and design of the landscape, yet without a direct understanding of the site-specific impact of these legislative changes. (ALLAN 2020) Each of these areas can benefit from spatial models that simultaneously combine the understanding of a landscape with and without fire, including its ecologies, cultural significance, risk and modes of maintenance and mitigation.

The research is evolving into the space of landscape response, where the potential of landscape architecture to combine planned regrowth, influence future landscape management and adaptive landscape use. This will require the ability to continually survey, reassess, simulate and communicate the risks and potentials to local communities in a clear and convincing manner, drawing on past events and direct example, as well as strengthened interdisciplinary and community collaboration. The virtual assembly of spatial datasets have the potential to become a crucial phase following such a fire event. Such a forensic reconstruction enables the simultaneous representation of complex site ecologies, built structures, infrastructures and spatial zoning rules. These models are forming a crucial tool to support the complex and sensitive process of response, repair and transformation that followed the 2019-2020 fire season events with the local Rosedale Community and its preparation for inevitable future fire events.

Acknowledgements

Many thanks to the local Rosedale residents including the Yuin elders and community for their assistance and collaboration, as well as external data providers FUGRO and Geospatial Intelligence on behalf of the NSW Government, and co-lead on the research Dr. Penny Allan.

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