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MSc in Geographic Information Science

Landscape Recreation of Viking-Age Iceland

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Content

This dissertation has two main components: Part I contains the main Research Paper focusing on the creation of a land cover model. This is followed by Part II, the Supporting Document, which contains an extended methodology as well as an investigation on creating a 3D landscape visualisation of the model, for increasing public engagement. The sections will be cross referenced: Part I (Maily, 2023a), Part II (Maily, 2023b).

Part I - Research Paper: *Navigating Uncharted Lands: Understanding Iceland's Past through Landscape Recreation*

Part II - Supporting Document and Appendices

PART I - Research Paper

Exploring Uncharted Lands: Recreating Iceland's Lost Forests

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Exploring Uncharted Lands: Recreating Iceland's Lost Forests

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Abstract - As Norse sailors settled in Iceland, they were faced with a land of ice, fire and forests. Yet Iceland's landscape is now well-known for lacking trees, a situation which only amplifies the negative effects of climate change and soil erosion. To reverse this situation, efforts are made to plant and grow new forests, but a drop in funding has slowed the progress considerably. To stimulate public engagement, this work therefore proposes to develop a land cover model of Iceland's past landscape, visualising its natural forests to promote afforestation efforts. This paper first reviews the previous attempts at recreating the pre-Landnám landscape (land take phase of the settlement). Using literature describing the factors contributing to the landscape changes in Iceland, these attempts are discussed to highlight their strength and understand their limitations. Then, using a novel methodology that incorporates soil, wetness and vegetation, a model of the potential current-day land cover of the wider Thingvellir area is developed. This model is then reviewed against official land cover datasets, to highlight key findings. Finally, by incorporating archaeological and historic data, the model is revised to generate a new pre-Landnám land cover model. Several insights were made, despite the model's limitations. First, the current-day model, and the comparison with official land cover, permitted the identification of areas where afforestation efforts could be successful and prioritised. Second, the pre-Landnám model suggests a more diverse landscape compared to those previously described in the literature.

***Keywords* –** Iceland, settlement, landscape recreation, land cover model, forest

1 Introduction

The landscape one encounters in Iceland today impresses with its majestic and vast openness, but the Iceland the Norse settlers encountered 1150 years ago would have been vastly different. It seems almost unimaginable today, with only 1.5% of its land covered in forests (Traustason and Snorrason, 2008), that the country was once "covered with woods between the mountains and the seashore", as Ari Þorgilsson claimed in the early 12^{th} century (2006). These landscape changes have led to large scale erosion, increased wind speed and dust storms, with continuous loss of arable land and destruction of native habitats (Shotter, 2022). Iceland has potentially lost up to 30% of soil since Landnám (land take phase of settlement), leading to over 40% of Iceland now being classified as barren desert, despite their efforts to slow down erosion (Arnalds, 2015).

As the global climate is warming, Iceland is facing its warmest summer temperatures during the Holocene. Understanding the natural habitat in the area could improve the management and restoration efforts, for example, by deciding on areas that have the highest potential for reclamation. With the increase of forest cover, Icelandic Forestry (Skógur) is trying to rebuild what was lost in a way that will benefit the country, by improving the ecosystem resilience, preventing further soil erosion and decreasing dust storms, while also creating a carbon sink, areas of recreation, and a sustainable forest industry (Eysteinsson, 2017).

But at the current rate, the forest cover is expected to only rise by 1% within the next 70 years, putting the target of 12% by 2100 out of reach (Eysteinsson, 2017). To generate the necessary funds, public engagement must be improved, particularly that of the large number of tourists travelling to Iceland every year (2.2M predicted for 2023 (Bjarnadóttir, 2022)). This study aims to create a model that will support a better understanding of the landscape early settlers would have encountered, to improve current landscape recreations and visualisations for the wider public and increase engagement.

Past studies have researched the environmental and human impact on Iceland's environment, through diverse approaches in the fields of archaeology, tephrochronology, and pollen studies, but thus far the research has been lacking detailed studies of what the archaeological landscape might have looked like. Reconstructions have been largely siloed into their respective disciplines and are limited by their simplification, scale, location or focus on a single species. Country-scale models often overestimate the forest cover while underestimating the diversity of the landscape, particularly in wetland and mountainous areas. Whereas farmstead-scale studies are too narrow to develop a picture of the wider landscape. This paper is attempting to overcome these issues by creating a region-scale model that combines past research with current environmental data and historic documents to fill in knowledge gaps when creating a landscape recreation.

Research Question

The evaluation of this project will address two research questions:

RQ1 What are the strengths and limitations of pre-Landnám landscape recreations in the literature?

RQ2 How well can current-day environmental data sets, with the addition of archaeological data and historic documents, support a new model of the pre-Landnám landscape?

To that end, this paper will:

- Review the literature on factors contributing to landscape changes in Iceland and use this knowledge to assess the landscape recreation models previously developed.
- Critically evaluate environmental datasets about the wider area surrounding Thingvellir and the capabilities in merging those into a current-day model of the potential land cover.
- Re-imagine the pre-Landnám landscape in area surrounding lake Thingvallavatn at the time of settlement by including historic and archaeological data to the current-day model.

2 Background

This section highlights the existing literature relevant to this paper. After presenting the specificities of the Icelandic landscape, it pays particular attention to the wider area around lake Thingvallavatn – the chosen area for this study. It then discusses previous attempts made to model the archaeological landscape in Iceland.

The Icelandic Landscape

Iceland has a harsh environment, isolated in the north Atlantic, it took time for plants to established themselves after the end of the last Ice Age, 10,000 years ago. At the time of settlement the temperature and vegetation had just reached its maximum (Erlendsson and Edwards, 2009; Gathorne-Hardy et al., 2009), before it slowly dropped towards the 13^{th} century and reached its post settlement lowest in the 15^{th} century (Hartman et al., 2017; Gathorne-Hardy et al., 2009). The boreal climate, with little snow cover in the lowlands (below 400 m above sea level (m asl)), and lack of permafrost, in addition to the absence of grazing animals allowed for the vegetation to adapt to this specific environment (McGovern et al., 2007).

The grazing animals and agricultural practices the settlers introduced after A.D. 870 changed this landscape from an estimated forest cover between 15% and 40% (Ólafsdóttir et al., 2001; Dugmore et al., 2009; Smith, 1995; Trbojevic, 2016) to 1.5% today (Traustason and Snorrason, 2008). The total vegetation cover changed from 54%-65% (Arnalds, 1987; Ólafsdóttir et al., 2001) to 28%-45% today, depending on the classification (Dugmore et al., 2009; Arnalds, 2015).

Vegetation cover is crucial to stabilise and trap the fragile andisols, which make up 89% of Iceland's soils (Arnalds, 2004). But due to the lack of large vegetation with sufficiently deep roots, erosion of large portions of soil has led to large scale landscape changes, with 15%-30% of soil lost since settlement, and over 40% of the country now being classified as a desert (Arnalds, 2015).

For better comparison between European countries the CORINE land cover classification was used to update Icelandic classifications. The CORINE classification however limits forests to trees that reach a minimum height of 5 m, Iceland received an exemption and it was lowered to 2 metres (Traustason and Snorrason, 2008). Following the classification in Table 1: 59% of Iceland's forests are Moors and heathland, 19% Transitional woodlands shrubs and 15% actual Broad-leaved forests.

Table 1: *Icelandic to CORINE land cover classification comparison.*

Icelandic	CORINE	Height
Natural birch woodlands	Broad-leaved forests	>2m
Natural birch woodlands	Moors and heathland	<2m
Transitional woodlands shrubs	Young forest plantation	<2m
Mixed forest	Mixed plantation and birch woodland	>2m

The low size of the only native forest forming species – Downy Birch *(Betula pubescens)* – is due to hybridisation, unfavourable environmental conditions and/or grazing which leads to low, multi branch "shrubs" that reach 2 metres in height, rather than reaching 12 metres with a single trunk (Smith, 1995; Shotter, 2022).

Study Area

Early settlers were attracted by the natural resources along the west coast, which was followed by a spread inland for farming and grazing, particularly along river valleys and in the south (Hartman et al., 2017; Vésteinsson et al., 2006). This early period of the settlement is referred to as Landnám, the time of land take. Their survival depended on strong collaboration within the community, which was often made out of family and kin, and the formation of economic trade networks (Pálsson, 2018; McGovern et al., 2007). According to traditions they formed regional gathering sites, assemblies known as *Thing* which were created in areas around settlement concentrations, near water courses, islands or peninsulas (Sanmark, 2022).

In A.D. 930 the parliament – *Althing* – was created at *Thingvellir* (eng.: fields of parliament), it marks the end of the Landnám period. Unlike the regional *Thing* sites, the chosen site had to be accessible to everyone across Iceland, while also being unclaimed, at a distance from farms and arable land to ensure safety and equality for the attendees (Sanmark, 2022).

Due to its historic, cultural and political importance, Thingvellir is now a protected National Park, and one of the first stopping point for many visitors. Its popularity and proximity to Reykjavik makes it ideal to reach people and increase engagement, which is why it was chosen for this study. The area was extended to approximately 45x45 km to include known areas of settlements, current forests and different vegetation types (Figure 1). Reykjavik and the coast were not included as there is too much uncertainty about the coast line at the time of settlement and modern large urban expansion provided difficulties for this study.

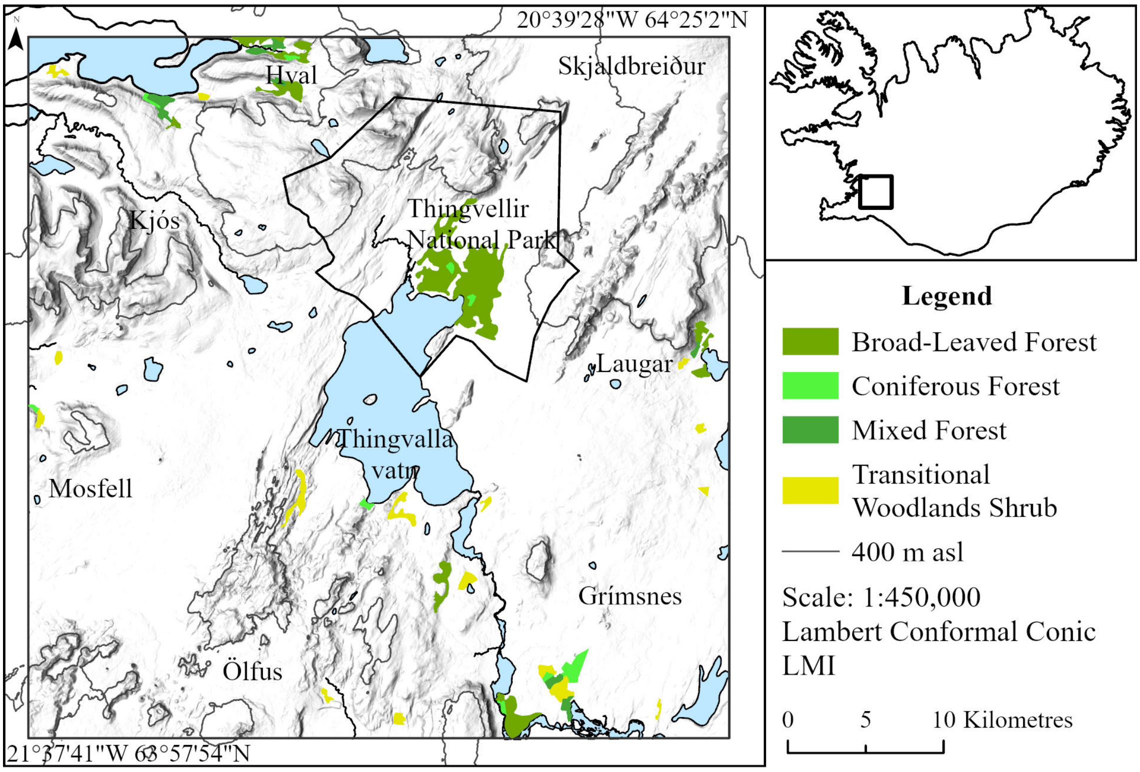

Figure 1: *Left: map depicting the chosen study area, with lake Thingvallavatn in its center and Thingvellir National Park north of it. Also indicated are current forest cover (Landmælingar Íslands, 2023), and generalised area names for orientation purposes. Right: overview of the study area within Iceland.*

Forests models

There is no consensus on the settlement landscape or methodology, which is the reason why the estimated forest cover varies so widely between studies. Trbojevic (2016) conducted an extensive literature review of past attempts, starting from early recreations based on historic descriptions stating that all of the lowlands were covered in forests. As the climate was similar to today, the tree line can be calculated as altitude temperature limit, but even this changes between studies: 300 m asl (Streeter et al., 2015), 400 m asl (McGovern et al., 2007; Dugmore et al., 2005; Traustason and Snorrason, 2008) and 600 m asl (Trbojevic, 2016). Basing a landscape recreation on the absence or presence of Birch forests has proven to be flawed and the assumptions used for it are usually based on political and economic reasons to further an agenda (Trbojevic, 2016).

The first attempts at a detailed vegetation map based on modern research where that of Eysteinsson at the Iceland Forest Service 2009, which distinguishes the forest limits in the boreal southern from that in the arctic north but did not distinguish vegetation types beyond a generalised Birch forest. This creates an overestimation of forest cover and misrepresents the landscape. Another attempt was by Einarsson and Gíslason, at the Icelandic Institute of Natural History (Talbot, 2012) which is commonly used in other studies (e.g. Shotter 2022). Even at a country-scale it differentiates woodland, dryland and wetland vegetation types into small patches. It has however been criticised for its mistakes, which led to an overestimation of the forest cover. The use of country-scale models of the landscape for regional or farmstead scale studies leads to over estimations of forest cover and a poor representation of the past landscape.

The Icelandic landscape is changing, and has changed since settlement, due to human activity and changes in the climate. While previous research has looked at country and farmstead scales separately, it appears that targeting a regional model between these scales could prove useful to better comprehend the diversity of its landscape, as well as including a wider selection of vegetation types. This study will attempt such a model by looking at the wider area around lake Thingvallavatn and the Thingvellir national park for its historical, cultural and political importance, and proximity to Reykjavik.

3 Data and Methodology

This section presents the data and methodology used to develop and validate the current-day land cover. The current-day model was created using environmental data from the Geodesy of Iceland, referred to as LMI (*Landmælingar Íslands*) and validated with current land cover data. These then formed the basis for the development of the pre-Landnám landscape model, adjusted through the use of archaeological and historic data.

Current-Day Model

Vegetation in Iceland depends on the soil, its wetness and its drainage capabilities (Arnalds, 2004), which several models reviewed for this study either lack or are overgeneralised. The model created in this study therefore adds – to the altitude already used in the other models – soil, wetness and slope as key indicators for the land cover classification.

For the purpose of this study, soil types are based on information from Thorsteinsson et al. (1971) and Arnalds (2004):

- *Histic / Gleyic and Brown Andolos*: fertile soils that feature wetlands in poorly drained areas, but shrubs and trees in temporarily wet areas, dry areas only support shrubs and smaller species;

- *Leptosols*: soils with limited vegetation;
- *Vitrisols*: upland desert soils.

Areas of young lava fields ($< 10,000$ years old) in the study area were classified separately. From direct observations in the field, it was noted that wet lava fields with Brown Andosols can support trees, whereas dry lava fields, usually associated with Leptosols, have limited vegetation.

To create areas of wetness, the data for both permanent and temporary wetness was extracted from the wetness dataset (Landmælingar Íslands, 2023). Other areas outside water bodies were considered dry. Due to the high diversity within the study area, and the purpose of a simple model, it was generalised to a cell size of 300.

The ArcticDEM (Digital Elevation Model) of 2 metre resolution was used to analyse the slopes in the study area (Porter et al., 2018). Due to the complexity of the landscape, the slope was calculated at a 30 metres resolution and re-classified into groups of: low slope (below 10°); moderate slope (below 30°); and high slope (above 30°). Wetlands were limited to the low slope areas. Altitude limits were set to 400 m asl for birch forests and 600 m asl for vegetation in general.

Based on information on the habitats of current native species (Kristinsson, Hörður, 2017), the following vegetation land cover classes were created for this model:

- **Wetland**, which range from peat bogs, predominated by Sedge's (*Cyperaceage*), to transitional areas were Tea-leaved Willow *(Salix phylicifolia)*, Dwarf Birch *(Betula nana)* and birch shrubs are found;
- **Forest**, which are dominated by Downy Birch *(Betula pubescens)* and associated undergrowth;
- **Shrub**, which classifies exposed and dry fertile soil areas that would not support trees or wetlands, these are dominated by birch hybrids/shrubs;
- **Moss** fields, for areas that do not support larger vegetation;
- **Sparsely Vegetated**, for areas at higher altitudes and/or slopes, commonly associated with Willows and Juniper (*Juniperus communis*); and
- **Unvegetated**, for highlands and/or poor soil that mainly support Lichen.

By combining classification for the soil (including slope, altitude and wetness) with that of vegetation land cover, the final current-day model divided the study area into the typology described in Table 2.

Model Validation

The current-day model was manually adjusted before validation. This step improved the visual distinction between patterns and reduced the impact of outliers and areas of artefacts that were created as a result of combining datasets.

The current-day model was validated in two ways. Firstly, by comparing the modelled wetland cover with the protected wetlands in Iceland and wetlands classified within INSPIRE datasets (Landmælingar Íslands, 2023). Secondly, by comparing the modelled forest cover with that of INSPIRE (classified as Broad-Leaved, Coniferous, Mixed Forest

Table 2: *Land cover classification used in the model.*

Type	Description
Wetland	Permanently wet areas in Histic-Gleyic and Brown Andosols, low levels of slope
Forest	Temporary wet Histic-Gleyic and Brown Andosols, slow to medium slopes, below 400 m asl Lava fields that are permanently wet
Shrub	Dry Histic-Gleyic and Brown Andosols, below 400 m asl Lava fields that are temporarily wet
Moss	Leptosols and dry lava fields Lava fields that are dry
Sparse Vegetation	400-600 m asl slopes
Unvegetated	Leptosol above 400 m asl, Vitrosols & above 600 m asl

or Transitional Woodland Shrub), and the Forestry (Skógur) forest dataset (Landmælingar Íslands, 2023). These comparisons primarily focused on calculating the percentage overlap between areas classification.

The purpose of these comparisons is two-fold. First it aimed to identify areas of discrepancy between the created model and the classifications from official sources. Then, with these limitations established, it aimed to improve and correct assumptions made when creating the classification for the pre-Landnám model.

Pre-Landnám Model

The current-day model was manually adjusted to better align with the validation data, before secondary data was used to infer the past landscape. The recreation was made on the basis that aeolian sediment transportation of sandy Vitrosols from the highlands and Andosols from erosion in the exposed lowlands increased after settlement and would have dried out areas in the lowland (Connors, 2010; Shotter, 2022). The landscape would have been wetter and therefore supported more forest along surface water lines.

Björn Gunnlaugssons map from 1844 is the earliest detailed visual record of the landscape, as such, its key features were used to indicate land cover extent. Inconsistencies were corrected based on archaeological evidence from the Mosfell Project (Connors, 2010). As there are only a limited number of records of archaeological settlement sites in the area (Schmid et al., 2021), georeferenced settlement sites from sagas (sagamap.hi.is) were used to indicate fertile land and possible human impact leading to environmental changes.

Historic and archaeological data were used as indicator only for changes in the landscape. The resulting model therefore presents a theoretical simplification of the landscape and should be read as such.

This section described the methodological approach used to create both the current-day and pre-Landnám landscape model of the Thingvellir region. First, a dataset of the current-day soil types (including wetness, slope and altitude) was created and then used to infer the land cover classification of the area. This model was then compared with official data sources to establish its limitations. Combined with archaeological and historic information on the likely presence of settlements, these constructed the basis for the pre-Landnám model.

4 Results and Discussion

This section presents the models created using the methodology above. In the first instance, the current-day model and its validation are discussed. Then, the pre-Landnám model is considered and reviewed alongside models previously created.

Current-Day Model and Validation

Forests could cover an estimated 20% of the area according to the model. Shrubs cover the largest part of the map with 27%, and 23% of the area is either too high in altitude or has poor soil quality and can only supports little vegetation. The Hval to Kjós to Mosfell and Laudar to Grimnes areas are fertile and dense with wetland, but divided by an area of elevated hills and young lava fields that form the boundary between tectonic plates (Figure 2). The lake forms the center of large flat open areas to the east and west of it, in which there is little protection from the elements and little surface water, and therefore forms dry Brown Andosols that likely would not support forests.

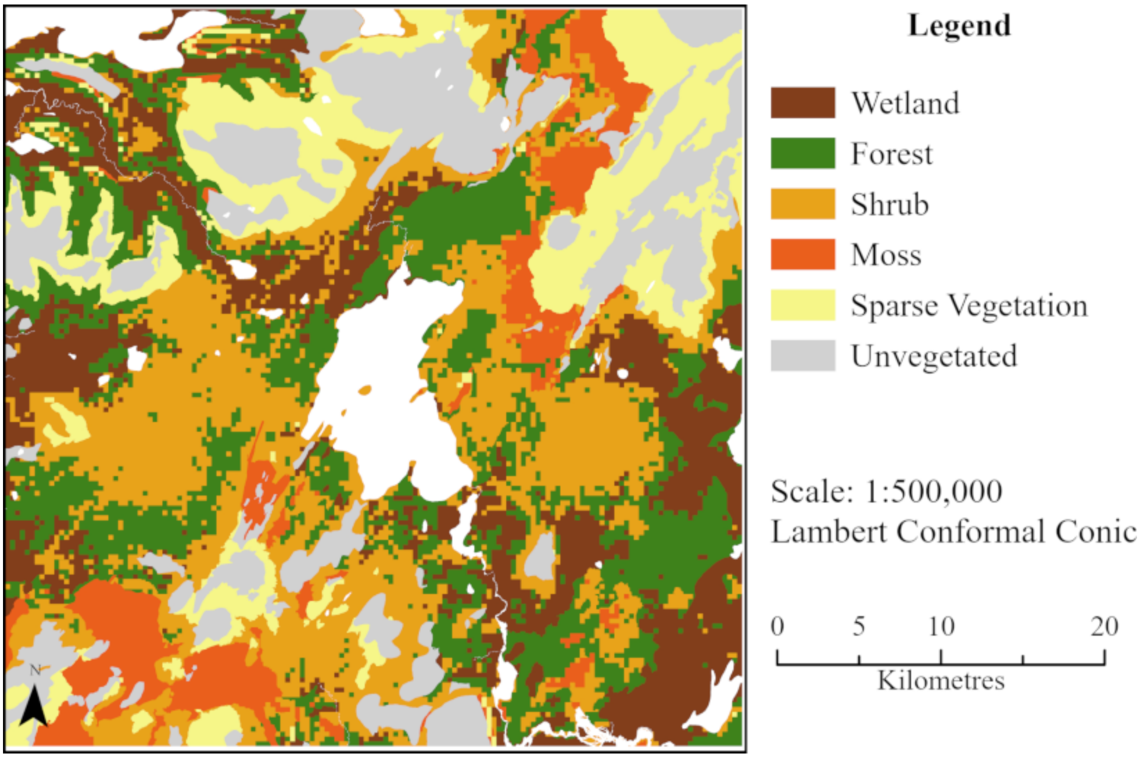

Figure 2: *Map of the current-day land cover model of possible vegetation extend, based on current-day environmental data.*

Despite being located south west of the Langjökull glacier, lake Thingvallavatn receives majority of its water through groundwater. The glacier discharges instead into the Hvitarvatn catchment, with the main river flowing through Laugar and Grimsness (Flowers et al., 2007). This could be the reasons for the wetness and fertility of that area compared to the area surrounding lake Thingvallavatn. Similarly, the protected river valleys along the Kjós and Hval coast are rich in vegetation, however salinity was not taken into consideration, these results should therefore be treated with caution.

Despite the two classes covering four to five times the area, the model missed 37% of current Wetlands and 61% of current Forests (Table 3). The Forest was underestimated in particularly wet areas of the wetland along the coast, Mosfell, Laugar and Grimsnes, as well as the lava field north of lake Thingvallavatn (Figure 3, left). The model also predicts larger forest cover in valleys along Mosfell, Kjós and Hval as well as the large drier areas east and west of lake Thingvallavatn. Highlands and young lava fields in Ölfus were low in vegetation, as expected.

Table 3: *Validation outcome comparing the current-day model to official land cover data for forests and wetlands.*

Land Cover	Predicted (km^2)	Official (km^2)	Accurate (km^2)	Missed (km^2)	Potential (km^2)
Forest	381	71	28 (39%)	43 (61%)	310
Wetland	324	78	49 (63%)	29 (37%)	246

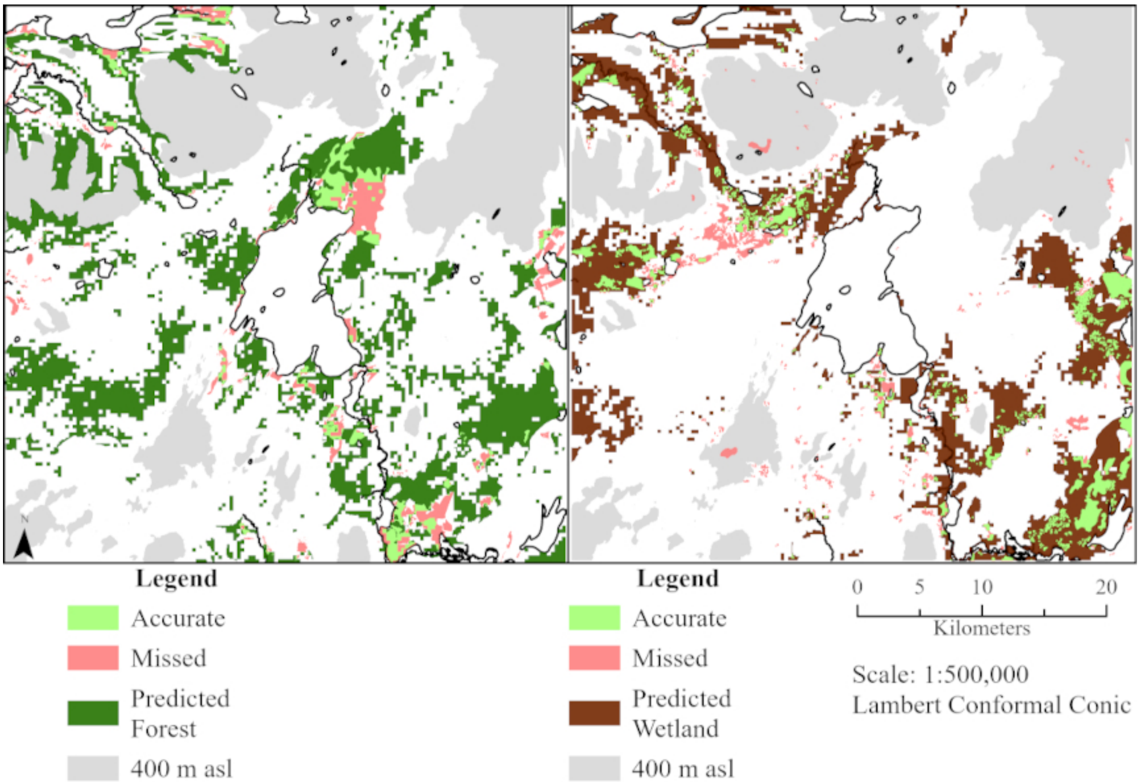

Figure 3: *Maps of the predicted Forest (left) and Wetland (right) areas, compared to the validation data. In light green are areas where the model accurately predicted the cover and in pink areas that were missed by the model.*

Wetness of the area between Mosfell-Kjós and lake Thingvallavatn, as well as the area surrounding the river south of lake Thingvallavatn was underestimated (Figure 3, right). Overall the predicted wetlands appear to be densest close to rivers and Histic-

Gleyic Andosols, Brown Andosol was less suitable than expected. However, they are also found in highlands and areas that do not currently support trees.

Two factors could explain the discrepancy between the current-day model predictions and official land cover data. First, the validation data is at a higher resolution, while many of the small areas were lost in the model due to the chosen resolution, and other areas became overestimated during the simplification process. Second, the model is predicting vegetation cover under natural modern environmental factors. The low overlap could simply be due to the fact that human activities regulate where forest can grow, rather than what would naturally support it. However, this highlights large areas that could be potentially used for afforestation efforts.

The current-day model also shows interesting differences between the young lava fields in the area. While the fields south of lake Thingvallavatn have low predicted vegetation, the lava fields north of the lake and at Grimsnes both have high shrub and forest cover (Figure 4). There could be several reasons, the main candidate being the soil accumulation and wetness coming from the glacial river north-east of Grimsnes, along with different land management. This demonstrates the uncertainty associated with predicting land cover of lava fields with the data used in the model.

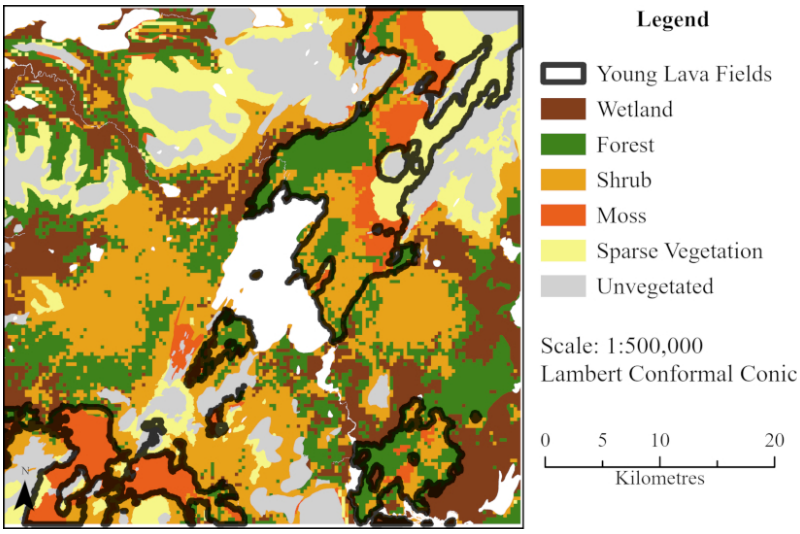

Figure 4: *Young lava fields (post glacial) in the area.*

Moreover, direct observations of the lava field north of the lake have revealed that, while officially classified as forest, much of the area is in fact covered by moss and dwarf birch with some shrubs (Figure 5). On the other hand, areas with forests are not labelled as such in the official land cover data. This shows the limits of using such dataset as ground-truth for validation and further explain the contrast observed between the current-day model and official data.

Pre-Landnám Model

The coastal areas are largely unchanged, apart from smoothing out the granularity of the current-day model (Figure 6). Wetland areas along the coast and Laugar and Grimsnes have a large number of saga settlement locations, suggesting fertile wet soil (Figure 7). As the area south of lake Thingvallavatn has four settlements, wetland areas were expanded to as large an area as the data would support, however they were reduced surrounding the

Figure 5: *Thingvalla lava field (10,200 years old), at Thingvellir National Park, covered by moss and dwarf birch, with birch shrub on larger flat areas in the background. ©Maria Maily*

young lava fields north of the lake and south of Mosfell. The largest change was the conversion of Sparse Vegetation areas east and west of the lake to forests. In Gunnlaugsson's map, those areas are overestimating lava fields and otherwise heaths, indicating shared grasslands used for sheep grazing. This continuous human impact on top of sand build up was taken as indication that it could at one point have supported forests.

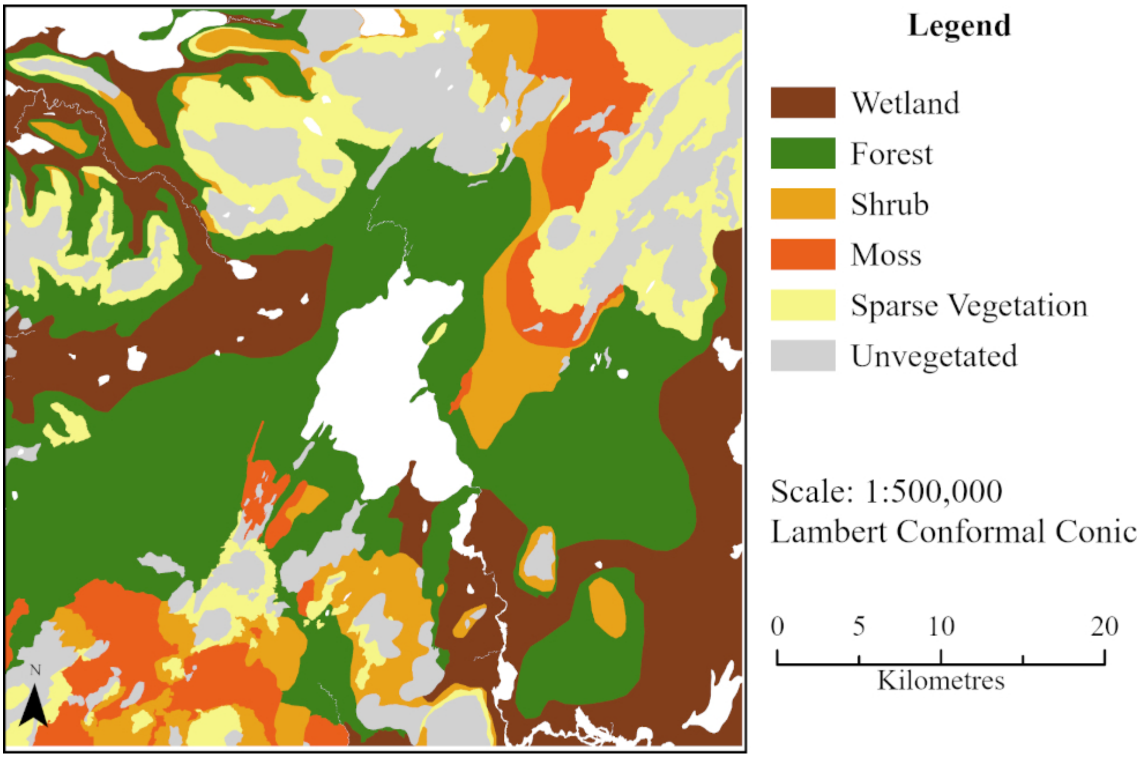

Figure 6: *Model of the pre-Landnám landscape.*

The lack of settlements at Thingvellir could be a sign of a prohibition to establish farms in proximity to the parliament, rather than based on environmental factors, which made the reconstruction difficult. The modern day forest cover in the area suggests that it could have supported larger forests at one point. Large sections of young lava fields were left at Shrub or Moss cover classification due to the lack of soil and wetness data limiting the likelihood of any difference.

Comparison to the Eysteinsson estimation (2009) was limited due to his model limiting the land cover to possible forest extent based on temperatures on a country scale. The

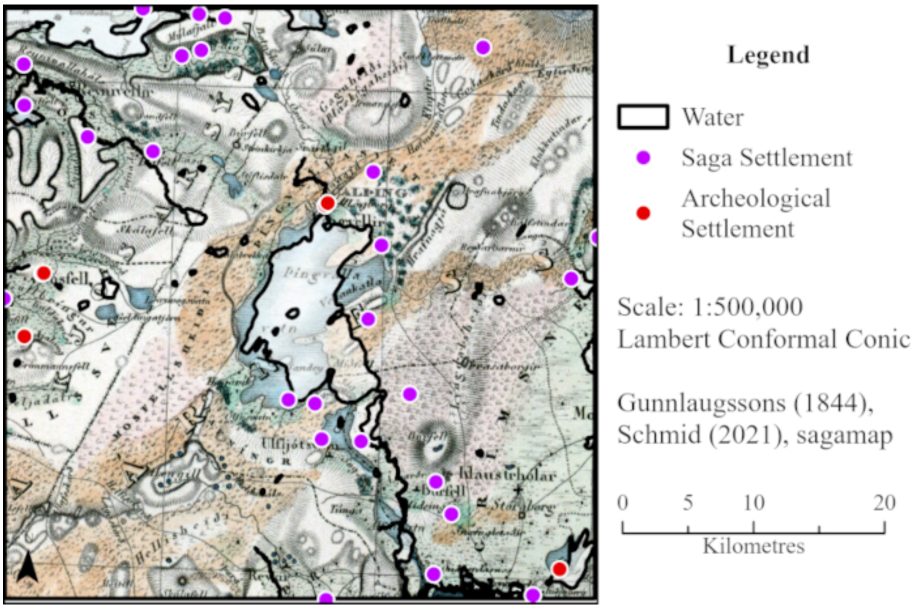

Figure 7: *Historic map by Gunnlaugssons of 1844, alongside archaeological and saga farm sites. Due to the inaccuracy of the historic map the current water bodies and major rivers were overlaid.*

7.6 °C settlement limit largely overlaps the Wetland, Forest and Shrub areas of the model, however, his model expands the forest cover at 9 °C to cover all Moss covered young lava fields and reaches altitude limits beyond the created model.

The Einarsson and Gíslason model (Talbot, 2012) allows for better comparison and overlaps in many areas. However, it underestimates the wetland areas compared to the created model. Around Mosfell, Grimsnes and coastal areas the wetland is particularly limited to less than current day extents. Their model classifies large areas of the lava fields as forest covered or at least dryland vegetation, which reaches into exposed areas.

When comparing the current-day model to the pre-Landnám model, the Forest area would have been 15 % or 277 km^2 larger than would be possible today (Table 4), whereas the Shrub cover would have been 18 % or 328 km^2 smaller. This highlights the impact deforestation and grazing have had on the landscape in the area since settlement.

Table 4: *Land cover comparison between the current-day and pre-Landnám model. The difference highlights the contrast between current-day possible extend and pre-Landnám.*

Land Cover	Current-Day		pre-Landnám		Difference	
	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)
Wetland	324	17	370	20	+46	+3
Forest	381	20	658	35	+277	+15
Shrub	499	27	171	9	-328	-18
Moss	146	8	148	8	+2	0
Sparse Vegetation	238	13	242	13	+4	0
Unvegetated	287	15	287	15	0	0

Limitations

The model was restricted to a simplified representation of the environment, the low resolution chosen for the current-day model resulted in low accuracy because many small areas were lost. The resolution was chosen due to the high diversity over large areas, resulting in more areas than can be handled by shapefiles. Future attempts would have to reconsider the resolution, simplification methodology, or data format. The high diversity of slope in the wide open areas west of the lake, which cause the majority of issues could have been due to the presence of thurfur and rofabards which would need to be confirmed before smoothing in a model (Dugmore et al., 2009).

Additionally, the wetland classification included both peat bogs and mires, as well as areas of transitions, i.e., shrub areas between true wetlands and Downy Birch forests that would not support either. Future attempts would have to find a way to distinguish them in the model similar to Shrub areas. For example, Histic and Gleyic Andosols split and only Histic and poorly drained Gleyic Andosols were classified as Wetland, whereas wet Brown Andosols would be areas of transition. Additionally, during the preparation, areas of water and temporarily flooded areas should be classified as permanently wet, as the classification set in this model led to an underestimation of wetlands along rivers and lakes. An additional step would be including salinity along the coastline, and what effects this would have on the vegetation.

The land cover classes were limited by the few selected representative species that are large in size, which were chosen for future 3D representation of the model. However, there are many smaller species, particularly in the undergrowth that are more common and could improve the classification accuracy (Sigurdsson et al., 2005; Erlendsson and Edwards, 2009). Therefore, more research is needed to establish what would have been common at the time of settlement apart from birch, and fieldwork could improve the resolution of the current land cover to better represent the area.

Furthermore, during a site visit, Downy Birch trees above 2 metres were observed at the Almannagjá gorge, at a slope larger than 30°. Additional data is therefore needed to distinguish table mountains with poor slope stability from slopes with stable soil, as slope alone did not prove very effective in estimating the vegetation cover on uneven ground. Instead of using slope, the following datasets could be considered as alternative indicators for vegetation cover. Firstly, erosion and wind data could point to exposed and protected areas, as well as areas of soil buildup due to eolian processes. Secondly, the presence of sheep, as grazing could be the reason for shrubs in the Thingvellir National Park, or low the number of Birch shrubs in dry and mossy areas (Arnalds, 1987). Lastly, descriptive place names – such as skógur - forest, víðir - willow, birki - birch –, as well as descriptions in the Book of Settlement (*Landnámabók*) could be included to indicate forests and their management (Dugmore et al., 2005; Smith, 1995).

This section described the results of the current-day and pre-Landnám models, including the validation by comparison to official data of forest and wetland cover. The current-day model indicates large areas that have potential for future afforestation efforts. While it presents limitations, improvements are also suggested. The pre-Landnám model compared well with other models and improved on them by introducing different data and classification groups that diversify the landscape and limit the overestimation of forest cover.

5 Conclusion

By understanding the natural habitat and landscape of Iceland, this study aims to support the many afforestation and restoration efforts combating, or at least mitigating, climate change and global warming impacts in the country.

This work present a novel approach to modelling land cover, developed by reviewing past model approaches and factors that have contributed to landscape changes (RQ1). This new methodology combines vegetation typology with soil classifications (including slope, altitude and wetness), to first create a current-day model of possible vegetation cover, which was compared against official datasets describing the current land cover. The comparison highlighted the limitation of the modelling process (notably the difference in resolution), but more importantly emphasised the areas were afforestation efforts could be further supported.

To understand what land cover could be, this work also attempted to see what land cover used to be – prior to human settlement on the island. This required the multi-disciplinary analysis of environmental, archaeological and historical data. The land cover model previously created was transformed to take into account evidence of the past landscape and land management since settlement (farm sites, locations of sites in sagas, historic map). The resulting pre-Landnám model demonstrates the dense vegetation and diversity of land cover prior to human impact.

By critically reviewing the models limitations and comparing the pre-Landnám model to previous recreations, opportunities for improvement were presented, notably in their accuracy by adding to the datasets used in their development (RQ2). More importantly, they provide a stepping stone towards the development of a baseline of what the Icelandic landscape looked like before settlement, and with it, a better understanding of the impact of human activity in its environment. By seeing what it used to be, witnessing its current state, and visualising what it could be, this study hopes to stimulate public engagement in the conservation and redevelopment of Iceland's natural habitats.

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PART II - Supporting Document

Extended Methodology and Visualisation

Maria Anna MAILY

August 2023

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Overview

This report is mainly divided in two sections. The first part contains supporting information on the creation of a model of the pre-Landnám land cover (Maily, 2023a), including the preparation of data, analysis of the methodology, along with description of first-hand observations.

The second part addresses additional Research Questions regarding the creation of a 3D visualisation of the landscape for the use of the wider public to increase engagement. It first looks at traditional GIS approaches, followed by the creation of 3D models and finally discussed opportunities for future work.

Finally, an overall project conclusion is presented, outlining the aim and objectives of the project (and their revision), the constraints that led to such revision and a summary of the major contributions of this work.

1 Creating an Environmental Model of the Past

This section contains an extended methodology for the current-day and pre-Landnám land cover models created for the study by Maily (2023a). First, it provides a rationale for the selection of the study area. It then presents the data sets used, how they were prepared and used in the model, as well as a discussion of the limitations they presented and approaches to accommodate for them. This is followed by a description of the native plant species considered for the model and a discussion of first-hand observations of the landscape in the study area.

1.1 Project Scope

At its genesis, the project set out to develop 3D models of Iceland's land cover during its settlement, with the aim to carry out an analysis of the development of routes between settlements. Given Iceland's harsh environment (earthquakes, eruptions, cold climates, etc.), it has been generally accepted that such connections were key to the survival of settlers. Understanding these routes could therefore hold valuable insights into the development of a sustainable society.

To narrow the project scope, a literature review was conducted on Iceland's settlement and the landscape changes that have occurred since. As the project initially set out to include an analysis of the routes developed during settlement, the aim of this review was to establish a list of candidate regions with enough connections and supporting evidence to carry out such an analysis.

Two regions quickly stood out: Thingvellir in the south-west and lake Myvatn in the north. The west coast, with a somewhat milder climate, attracted many early settlers for its natural resources, such as great auk, walrus, seal and trout (Vésteinsson et al., 2006; Dugmore et al., 2005). Similarly, the northern part of the country had many natural resources for settlers to survive and establish trade (Hartman et al., 2017; McGovern et al., 2007).

In recent years archaeological work has prioritised the north, leaving many sites in other areas unexplored, which is reflected in the few sites in the area surrounding lake Thingvallavatn, despite the large Mosfell Project (Schmid et al., 2021). In the end however, Thingvellir was chosen instead of Myvatn, due to its cultural and political importance. As the political centre – parliament site – it has many major roads and frequent traffic that can assist in our understanding of the settlers' relationship with the environment. Furthermore being at the centre of tourism and close to the capital means there is a greater audience and therefore possibility of future uses for a landscape recreation with a wider impact.

In the end, the project's aims had to be revised due to time and complexity constraints. While still developing a model of land cover recreation, the aims shifted towards providing resources and evidence to support the current afforestation efforts by Icelandic Forestry (Eysteinsson, 2017). Thingvellir turned out to be an even better candidate for such a task, being a key part in Iceland's natural resources preservation.

1.2 Data Preparation and Considerations

The nature of this study required the analysis of several datasets, spanning many disciplines. The list of datasets used can be found in Table 1. This section will describe the purpose of each dataset and how they were transformed for the study.

Table 1: *Data used in this project.*

Data	**Details**	**Source**
DEM	tifs for 47, 48, 57, 58 (2016)	Porter et al. (2018)
Environmental		
Elevation	INSPIRE Elevation (2016)	LMI (2023)
Soil	INSPIRE Geology (2009)	LMI (2023)
Water and Wetness	High Resolution Layer (2019)	LMI (2023)
Watercourse	INSPIRE Hydrography (2019)	LMI (2023)
Young Lava	INSPIRE Protected Sites (2019)	LMI (2023)
Historic and Archaeological		
Archaeological	Archaeological database	Schmid et al. (2021)
Historic map	Literary Society of Iceland	Gunnlaugsson (1844)
Saga Farms	Sagamap Project	Lethbridge (2023)
Validation		
Forest	Skógur (2015)	LMI (2023)
Land cover	INSPIRE Land cover (2016)	LMI (2023)
Wetlands	INSPIRE Protected Sites (2019)	LMI (2023)
Wetland area	INSPIRE Hydrography (2018)	LMI (2023)

1.2.1 ArcticDEM

The base of this study is a 2-metre resolution Digital Elevation Model (DEM) of Iceland, made available by the ArcticDEM Project (Porter et al., 2018). To cover the study area, the tiles 46, 47, 57 and 58 (Figure 1) were downloaded from the Landmælingar Íslands website (https://atlas.lmi.is/mapview/?application=DEM). A Mosaic was created in ArcGIS Pro and clipped to the study area.

Unlike a Digital Terrain Model (DTM) that represents the surface, a DEM includes vegetation and buildings, creating uncertainty in populated areas. As such areas like Reykjavik were avoided where possible. Geological factors provided similar problems

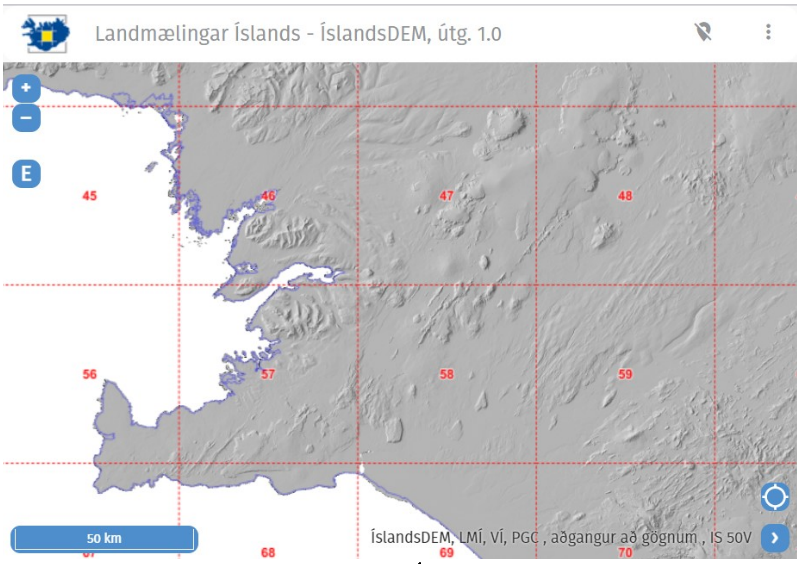

Figure 1: *The Landmælingar Íslands webpage map viewer.*

that were considered but not taken into account due to the resolution, time limitation and uncertainty.

Firstly, there would be a difference in surface height due to erosion (Dugmore et al., 2009), particularly a reduction in the uplands, and a build-up of the eolian transported sediment in the lower areas. Additionally, there could have been a considerable build-up of tephra from any of the over 200 eruptions since settlement (Hartman et al., 2017). Further detailed research would be needed to determine if the resolution would allow for such changes.

Secondly, the area is split by the western rift zone (WRZ), separating the North American plate from the Hreppar micro-plate (Sigmundsson et al., 2020). It is unclear how much it has changed and was not a priority for the study. Again further research would be needed to establish the impact of these changes, if any. Furthermore, the country has periodically sunken and risen as the glaciers have grown and receded over the centuries. This would have had a particular impact on the coastline, which also experienced considerable sea level changes (Vésteinsson et al., 2006). Such changes were not included, but the coastline was avoided where possible.

Lastly, the Öxará river was diverted before A.D. 930. Due to time limitations, this was also not included in the model but would have likely made a small difference of wetness distribution in the area surrounding it.

The high resolution of the DEM was chosen as it would be necessary for the later 3D visualisations, but over such a large area, this presented difficulties for analysis. The terrain displayed high complexity even within flat open spaces (Figure 2). The reason was not confirmed but could be due to vegetation cover, thurfurs or rofabards.

After testing different approaches the DEM was resampled to 30-metre resolution using the Nearest Neighbour technique, before reclassifying the data into groups of slopes below 10°, below 30° and above 30° (Figure 3, left). It was then converted to a vector file for further analysis. However, after inspecting the other datasets, the data was further simplified by turning it back into a raster at 300 cell size utilising maximum area assignment (Figure 3, right). This was done to reduce small areas in the simplified model of the landscape and match with the wetness data sets which provided similar resolution issues.

This simplification enabled the development of a simplified model for the purpose of

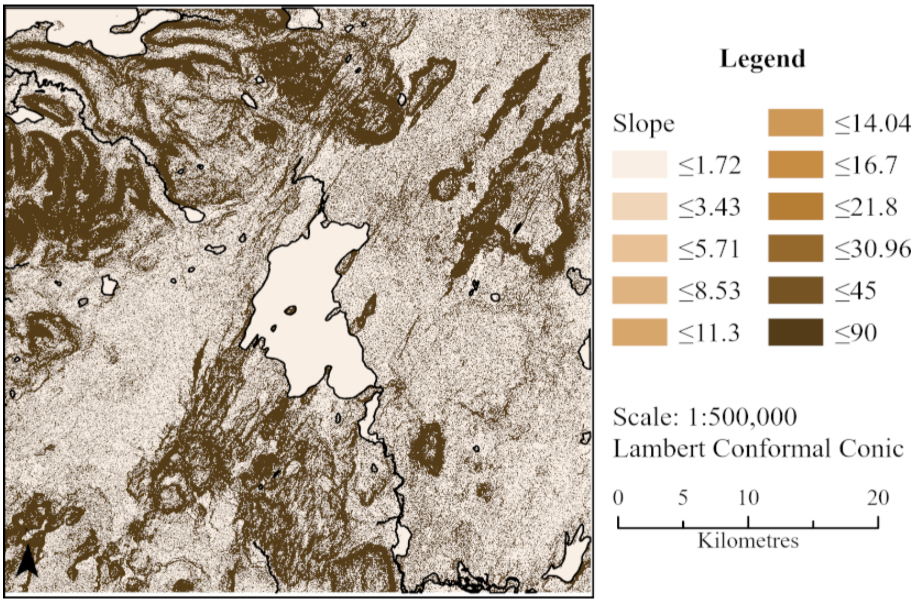

Figure 2: *Slope analysis of the 2-metre resolution DEM.*

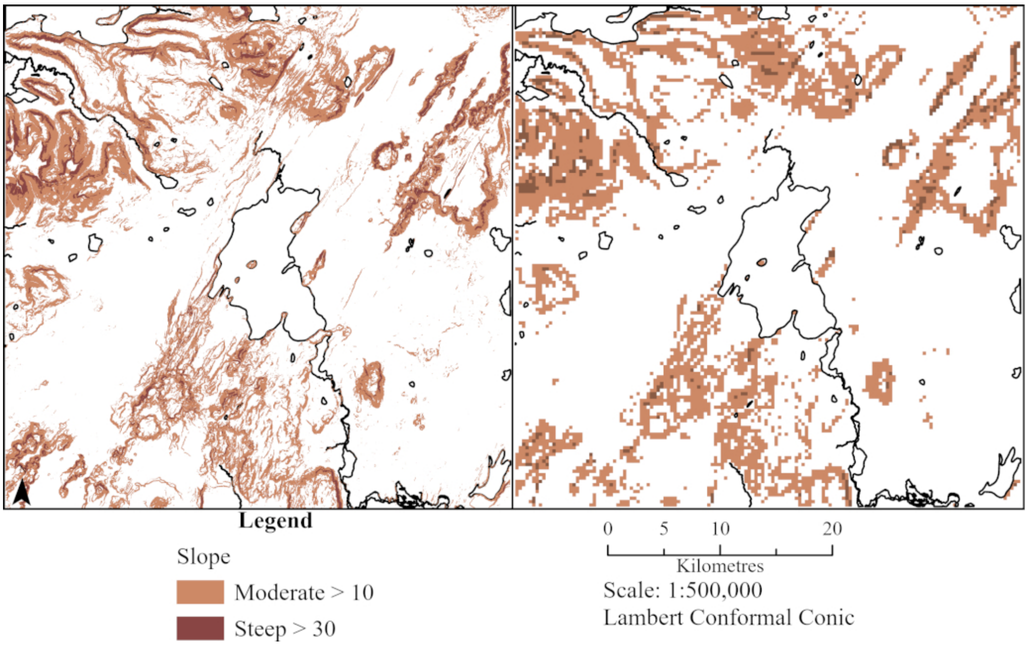

Figure 3: *Simplification of the slope data. Left: 30-metre resolution. Right: cell size 300.*

the study but also proved to be too low in resolution to produce an accurate model for uses of smaller areas within the model.

1.2.2 Environmental Data

As much as possible, this project aimed to make use of freely available data. To that end, much of the data used was part of INSPIRE datasets hosted by the Landmælingar Íslands (Geodesy of Iceland) (Table 1). One of the key datasets was soil classifications in the area, unfortunately the data available is at a 1:500,000 scale and therefore intended to be an overview, rather than for a detailed model. The soil classification used was based on World Reference Base (WRB) information and work by Arnalds and Óskarsson (2009): Andic soils are Brown, Gleyic and Histic Andosols; Vitrisols (desert soils) are Cambic, Gravelly, Arenic and Pumice Vitrisols; Histosols, Cryosols and Leptosols are also present (Landmælingar Íslands, 2023). The only modification made to the data was the merging of Histic Andosols and Gleyic Andosols, to form the wet soils group in the model.

Young (post-glacial) lava fields were added as a sub-division of soil, as they were considered to have a considerable impact on land cover based on first-hand observations (Section 1.3). Post-glacial lava is protected under natural conservation law Article 61, meaning that the location, age, name and volcanic system are published as part of the natural heritage register (Landmælingar Íslands, 2023). The boundaries of the lava fields were dissolved to create larger polygons, rather than treat each individual, as age was not considered a determining factor in the study.

The second key environmental dataset was the Wet and Wetness raster of 20-metre resolution. It reflects the occurrence of water and wet surfaces between 2009 and 2015 (Landmælingar Íslands (2023)). It had a similar complexity to slope (Figure 4, left) and was therefore simplified. Permanent water, temporary water and dry areas were removed through reclassification, leaving permanent wetness and temporary wet areas. It was simplified in the same way as slope, to a cell size of 300 (Figure 4, right). The position of the Slope and Wetness layers were slightly adjusted as the grid cells did not fully overlap, introducing a slight inaccuracy of placement. However, as the cells are at a large cell size and simplify the environment this step was taken to ease further analysis. In future attempts, this would be avoided by using the data at a smaller cell size.

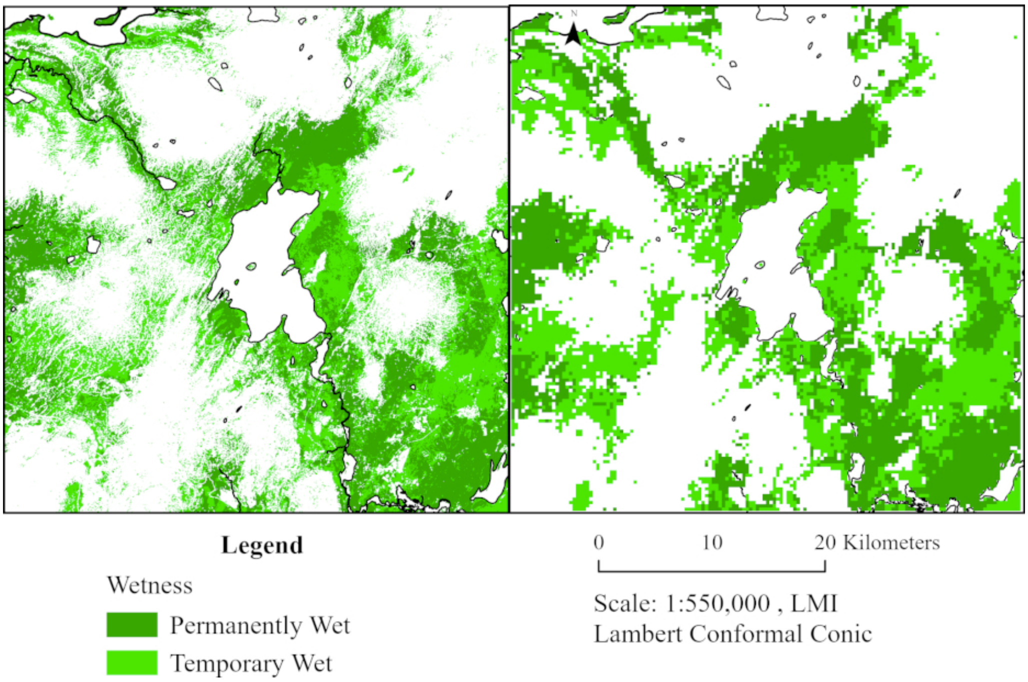

Figure 4: *Simplification of the wetness data. Left: 20-metre resolution. Right: cell size 300.*

Furthermore, watercourse body polygons, coastline and study area polygons were used to limit the extent of the datasets and remove land cover from larger water bodies. Indicating these across the models makes visual analysis and orientation easier. Watercourse lines were used as an indicator of drainage ditches dug in wetland areas when creating the pre-Landnám model. These are easily distinguished from natural watercourses as they form dense patches of parallel lines. Lastly, the 400-metre and 600-metre data of the elevation dataset were selected and polygonised to set tree and vegetation boundaries for the model.

For the model validation, forests land cover data was extracted from the INSPIRE Land cover dataset and merged with the forest dataset from Skógur before being overlaid with the model to perform an intersect analysis. The same was done for the wetland data from INSPIRE Protected Sites and Hydrography.

1.2.3 Historic and Archaeological Evidence

There are no written records dating to the settlement period of Iceland, as literacy only became widespread in the 12^{th}-century (Hartman et al., 2017). But it has a long and rich oral tradition, sometimes reaching back decades before the settlement of Iceland. These stories – family sagas – contain the earliest descriptions we have of the environment the settlers encountered. They describe lush forest and fertile land which attracted many settlers to its shores. These sagas present an opportunity to view the past through their eyes, but at the same time present a multitude of problems.

Their use as primary source of information has declined over the past decades as research has shown that the stories were influenced by medieval politics exaggerating facts for their own gains (Hartman et al., 2017). They are particularly sparse in their descriptions of the environment, however they provide locations of settlements, indicating fertile land and resources.

The Icelandic Sagamap Project has georeferenced as many sites as possible and granted permission to use this data for this study (Lethbridge, 2023). The map was filtered for the Farm keyword of all texts, and the GPS coordinates, name and texts they appeared in were downloaded (Figure 5). For this study, the GPS points were used as indicators of fertile land and areas of heightened human impact. However, in future studies the original texts could be analysed in more detail to gain a deeper understanding of the settlement and land use (e.g., farming, grazing, etc.).

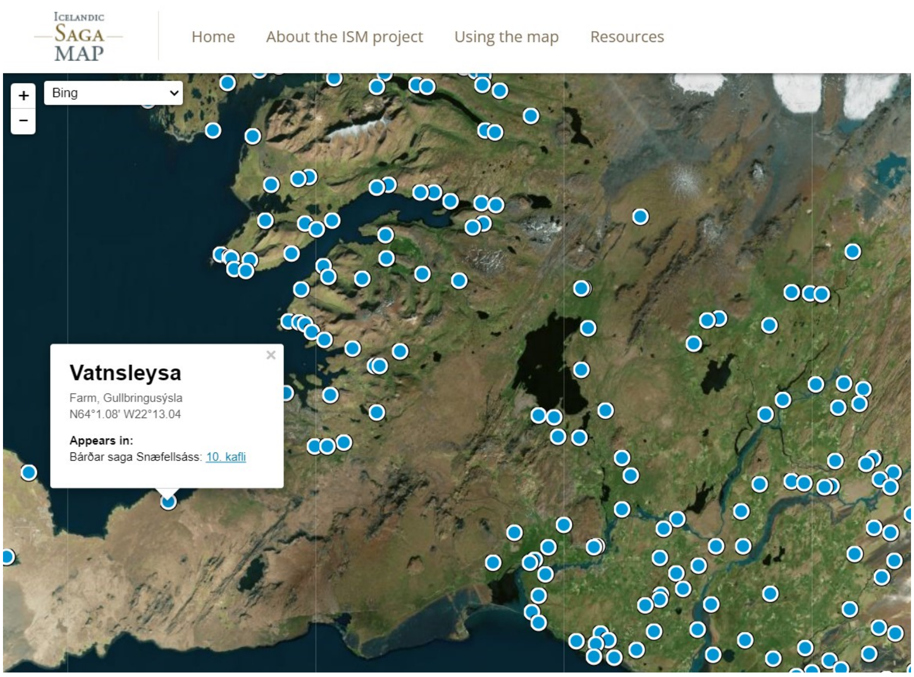

Figure 5: Screenshot of sagamap.hi.is, displaying all farm points. The Vatnsleysa farm pop up demonstrates the associated data downloaded for each point.

Similarly, historical maps can provide a glimpse into the past, but the earliest maps only depict the coastline as they were intended for foreign trade. Icelanders did not need a description or visualisation of their surroundings: they either knew their country or depended on locals to avoid treacherous paths. Björn Gunnlaugsson was the first to truly survey and create a detailed map of Iceland. It was finished in 1844 and published in four parts by the Literary Society of Iceland around 1848, in Copenhagen. He was funded by the Danish crown and therefore limited by the crowns interests. Which meant he surveyed little beyond the coastal settlement cores and relied on information from locals and approximations to finish his map (Connors, 2010).

The map section of south west Iceland was georeferenced with 86 points, using 1st Order Polynomial (Figure 6, right), focusing particularly on coastline features and water bodies, as they have hard outlines. Lake Thingvallavatn and the surrounding smaller lakes provided greater difficulties as they were particularly inaccurate (Figure 6, left). One possibility is that there was little field survey done in the area due to the little number of farms and limited interest of the Danish crown in the parliament site. The second area of lower accuracy was the south coast. This area has seen most changes due to volcanic eruptions and associated jökulhlaups (glacial outburst floods) from the Langjökull, Eyjafjallajökull, Tindfallajökull and Mýrdalsjökull glaciers (Flowers et al., 2007; Wells et al., 2022a,b), however this will have no impact on the study area.

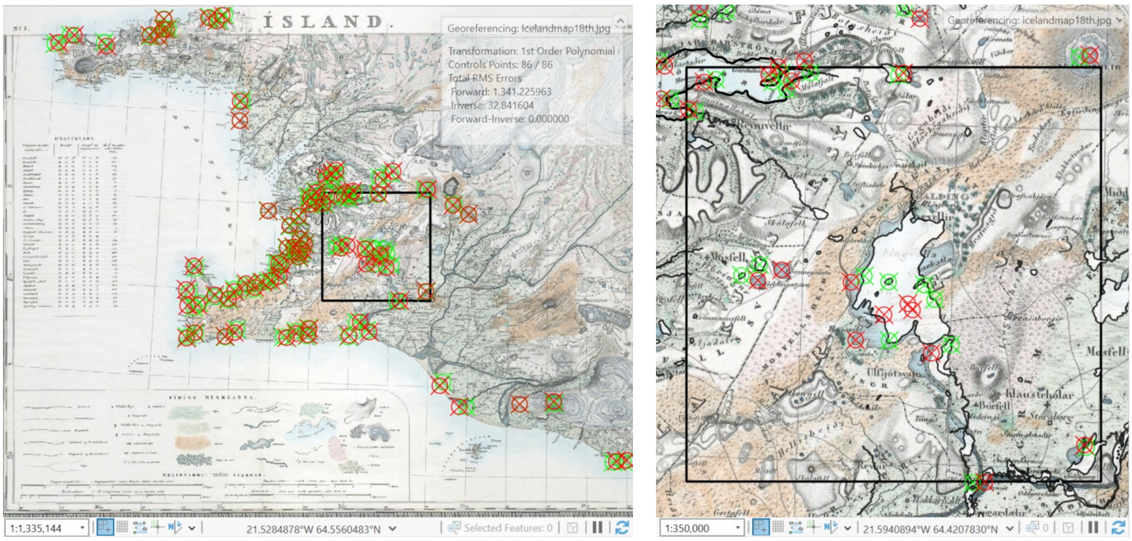

Figure 6: *Screenshot of the georeferenced Gunnlaugsson map of SW Iceland (1844). The study area at a larger scale is shown on the right, with water bodies and coastline overlain for better comparison.*

Despite the inaccuracies, the map provides indications of the environment at the time of drawing, it depicts areas of wetlands, heaths, lava fields, forests and slopes that can be used to further our understanding of the past landscape.

1.2.4 Native Vegetation

The study expanded on previous models by including a range of land cover classes to better convey the diverse landscape (Maily, 2023a), instead of focusing on the primary species – Downy Birch (*Betula pubescens*). A lack of pollen or macro-fossil evidence is an ongoing issue in truly understanding the vegetation and particularly the underbrush, but based on the literature the following species were considered (Kristinsson, Hörđur, 2017; Sigurdsson et al., 2005; Erlendsson and Edwards, 2009):

- Downy Birch (*Betula pubescens*) can reach up to 12 m, prefers moderately dry soil and can be found in the lowlands up to 400 (Figure 7, right). Trunk spacing was estimated to be about 50-75 cm (McGovern et al., 2007).
- Dwarf Birch (*Betula nana*) only reaches 20-60 cm in height, is found on wetter soils and Dwarf shrub heaths.
- Birch Shrubs can either be small birch trees, that due to environmental conditions, forest management or grazing impact have grown low, shrubby and multi-branched or are a consequence of hybridisation of Downy Birch and Dwarf Birch. They are commonly found in windier areas and poorer soil and only reach 2 metres (Figure 7, left).
- Tea-leaved Willow (*Salix phylicifolia*) between 1-5 m high, is common in meadows, an important species along river banks, slopes, and moist-soiled heathland. Furthermore. it is found in the undergrowth of damp woods.
- Juniper (*Juniperus communis*) ranges in height between 30-120 cm, found in heathland, on lava fields, on hill edges and as undergrowth of brushwood.
- Rowan (*Sorbus aucuparia*) can reach 12 m, associated with Birch forests and gorges.
- Furthermore there are moss, sedge and lichen species associated with the landscape but these will not be represented in model attempts.

They were assigned to the land cover classes as listed in Maily (2023a).

1.3 First-Hand Observations

A visit to the study area was undertaken in May 2023 to gain further insight and gather an understanding of the study area in situ. Despite seasonal difficulties of late spring snows and lack of foliage, which made distinguishing shrubs from the soil difficult, differences of land cover were clearly visible between areas. West of lake Thingvallavatn, the land is exposed with little visible vegetation, whereas the lava field at Thingvellir is covered in patches of shrubs and trees (Figures 8 and 9). Traveling from the sparse vegetated lava fields east of lake Thingvallavatn towards lake Laugarvatn, the vegetation and forest cover visibly increases (Figure 10). The densest forest cover was in Grimsness (Figure 11), although they are modern coniferous plantations. Frequent strong winds in the Thingvellir area (anecdotally) and low soil accumulation, due to Langjökulls glacial outflow bypassing the area, were the two main factors identified for the contrasting vegetation cover between the study area and the neighbouring valleys.

These observations permitted several insights that ultimately influenced the final direction of this project. The disparity in vegetation revealed that a naive assumption that forests could grow anywhere – as historical sources like the Íslendingabók would suggest (Þorgilsson, 2006) – is an oversimplification of the reality. This motivated the integration of soil and wetness data for the creation of the model. Witnessing lava fields in person, it was made apparent that – contrary to initial assumptions – trees could hardly grow on such terrain, given the small amount of soil on top of the lava. This led to adjustments in the soil and wetness data to account for this observation.

Figure 7: *Birch shrub (left) and birch trees (right) in the Thingvellir National Park. Pictures by Maria Maily.*

Figure 8: *Wide open area west of lake Thingvallavatn, potential thurfurs. Picture by Maria Maily.*

Figure 9: *Coniferous stands and birch trees at the Almannagjá gorge, small patches of birch trees and shrubs towards the distance. Picture by Maria Maily.*

Figure 10: *Shrub cover and soil quality visibly improving towards Laugarvatn. Picture by Maria Maily.*

Figure 11: *Coniferous forests at Kerid Crater, Grímsnes. Picture by Maria Maily.*

2 Creating an Engaging Landscape Visualisation

The pre-Landnám land cover model was created to better communicate the environment Norse settlers would have encountered to the public, in an effort to increase public engagement and support afforestation effort. However, for many non-expert users, traditional Cartesian maps that depict landscapes from a top down view are unhelpful in gaining a deeper understanding of the environment and creating a mental image of a landscape unfamiliar to the them. Nevertheless, effective and engaging visualisation of information is an important communication tool, particularly in environmental protection and forest management (Bell, 2001). Visual cues representing the land cover can be more intuitive than flat colors often used in two-dimensional maps. To improve on this, any visualisation attempt trying to convey a large amount of complex information has to consider needs of the data, software limitations, accessibility, ease of use and quality of the output to create an improved method of communicating information.

After an analysis of different landscape visualisation approaches within traditional GIS tools such as ArcGIS and QGIs, alternative 3D visualisation tools were considered, as virtual and physical 3D visualisations have been effective in communicating complex landscapes to non-experts in the past (Appleton et al., 2002; Anderson et al., 2018). This work addresses the following research question[1]:

RQ3 What are the opportunities and limitations of traditional GIS and novel 3D applications for landscape visualisation?

To that end, the following objectives were set:

[1]**RQ1** and **RQ2** are addressed in Maily (2023a)

- Evaluating the capabilities of traditional GIS tools for visualising a large forested landscape.
- Testing alternative tools for 3D visualisations of large landscapes.

2.1 Traditional GIS Approaches

To communicate the findings of the current-day and pre-Landnám models to an academic audience, complex hues representative of the classes were used. A dark to light value hierarchy reflects their importance, drawing the eyes to the dark colours of Wetlands and Forests and away from the lightest colours of Sparse Vegetated and Unvegetated (Maily, 2023a). This choice sacrificed considerations such as grey scale or color accessibility limitations. However, this was done to aid the user in interpreting the information without a repeated reference of the key. Furthermore, such a 2D simplified representation hides the terrain and important landmarks that would convey the complexity and aid orientation within the landscape. However, as it is a model of the pre-Landnám landscape settlement locations would have confused the model.

As the size of the study area was too large for software to render, it was clipped to an area of 25x25 km^2. Thingvellir is at its center, covering the National Park north of it, as well as areas to the east and west of the lake, as this would be covered in forests and of interest to visitors (as seen in Figure 12). The applications used for this where ArcGIS Pro 3.1.1 and QGIS 3.3, the methodology used would work in both applications.

2.1.1 Picture Fill

The symbology of Gunnlaugsson's map of 1844 conveys the landscape more effectively to users unfamiliar with the landscape, by including hills and slopes as well as using symbology that visually represents the environment – such as green heath and wetland, dark green forests and contrasting orange lava fields. White empty spaces between areas aid in separating them and highlighting unvegetated hHighlands. However mires and heathland are very similar and often overlap which makes it difficult to distinguish them, and large names make identifying the class below them difficult.

In an attempt to improve on the map of the model, the same symbology was used as a picture fill to make it easier for the user to identify the classes without the need of a key, as well as adding hill shade to indicate altitude changes (Figure 12). However, due to the image resolution and scale of the map this was unsuccessful in improving the map. Furthermore, the colours are too similar in shade to distinguish, and the hill shade not as visually distinguishable as Gunnlaugsson's map.

2.1.2 Polygon Extrusion

Utilising ArcGIS Pro local scene allows for a representation of the data in three dimensions, thereby potentially increasing the effectiveness and engagement of the user through interactivity. It allows for a change in direction and scale, conveying a better impression of how the vegetation would have filled the landscape. The increasing importance of visualising information in this way is reflected in the rise of 3D capabilities in traditional GIS tools, digital twins and specific tools such as ESRI CityEngine.

The model was visualised with the use of polygon extrusion from the features base to better reflect the landscape underneath it. For the purpose of the prototype, the following

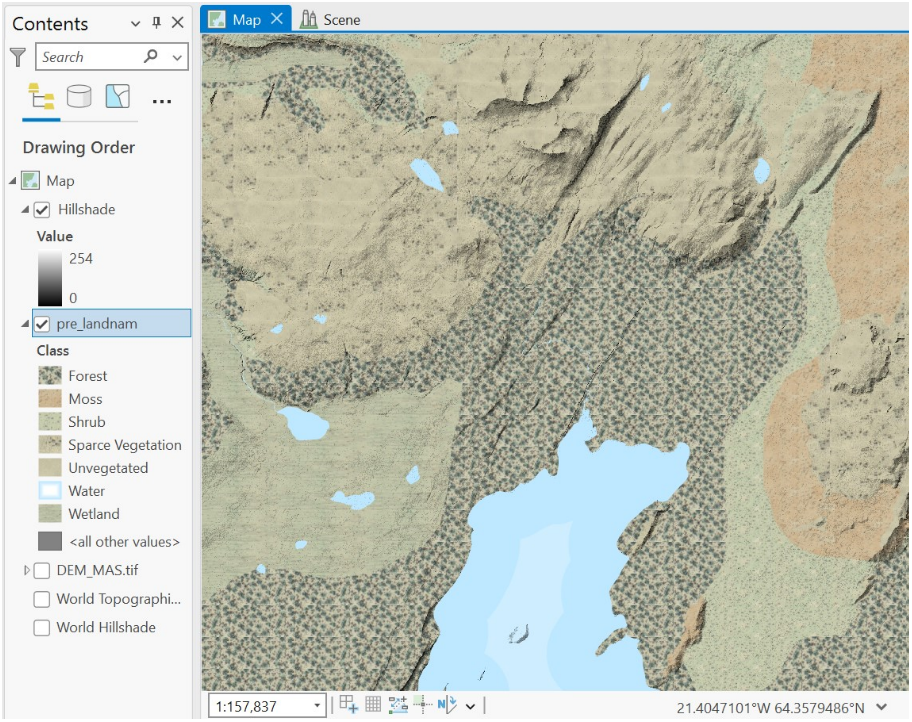

Figure 12: *Screenshot of land cover model symbolised like Gunnlaugsson's 1844 map, layered with hillshade.*

heights were used for the land cover classes: Forest 12 m, Shrub 2 m, Sparse Vegetation 5 m and Wetland 1 m (Figure 13), based on the vegetation data discussed in Section 1.2.4. Standard 3D symbology was used for the polygons picking darker greens for Forest and Shrub areas, lighter green for Sparse Vegetation, shades of brown for Wetlands and Moss and grey for Unvegetated. The navigation in ArcGIS Pro local scene is not very intuitive for non-GIS users and is slow in loading such a large landscape, which could lead to user frustration. Furthermore, the visualisation displayed issues such as streaks and sharp edges on flat surfaces, creating a surreal landscape. As the model would have to be in ArcGIS or a video clip of a flyover, this visualisation has neither the detail nor scale for people to improve their understanding of the environment.

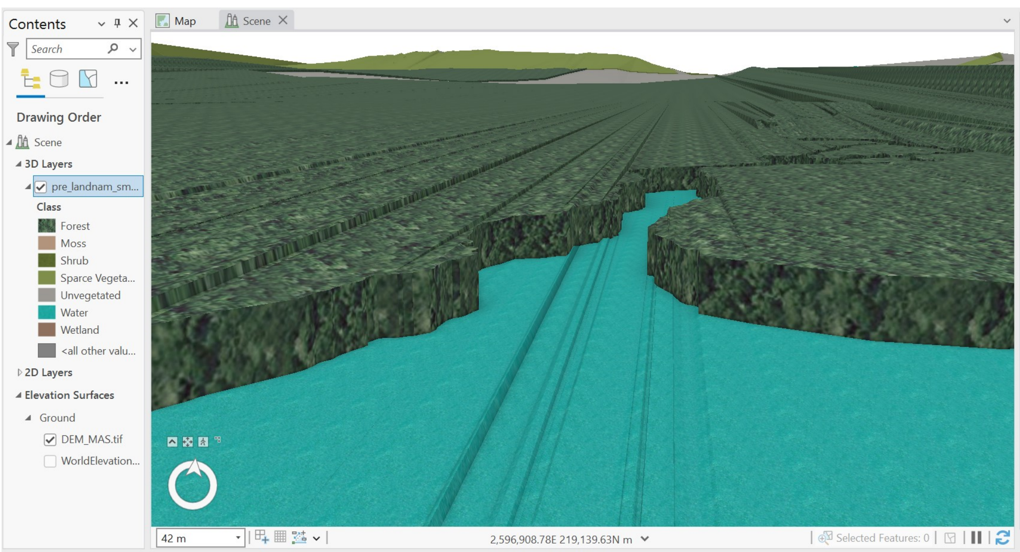

Figure 13: *Screenshot of polygon extrusion attempt in ArcGIS local scene.*

2.1.3 Random Point

As the modern landscape shows diversity in the trees and land cover, a polygon based visualisation struggles to convey the landscape in a meaningful way. Therefore the option of creating Random Points for the representation of individual trees was tested in QGIS. As this prototype was attempted before the pre-Landnám model was completed, a preliminary forest polygon within the Thingvellir national park was created. To create this forest polygon, the following assumptions were drawn from Trbojevic (2016): 10 m buffers were generated around water bodies to increase their visibility, areas above 400 m asl and above slope of 30° where erased, and a second polygon was drawn along the western boarder to represent wetlands. The resulting polygon had an area of 127 km^2. The Random Points inside Polygon tool was used setting the point count to 1 tree per m^2, resulting in 127 million points. With 5GB the file was too large to open, as the shape file limit is 2GB or 70 million points (Esri, 2023).

For the second and third iterations, modern day forest areas (Landmælingar Íslands, 2023) in the Thingvellir national park were used, as they are only 37 km^2 and should therefore be small enough for testing. First the polygons were merged to work with one large polygon but for the third iteration they were used as separate polygons. An attribute field was created to calculate area in m^2 and used as input for point count. Initial tries failed due to incorrect minimum distance of 1 m which was therefore set to 0.6 m (based on trunk spacing information (McGovern et al., 2007)). The final iteration succeeded and created a file of 1.65 GB. A Scalable Vector Graphic (SVG) file of the top down view of a tree was created in Inkdscape, for testing 2D symbology. However using the SVG as symbology at a 1.5 m real world unit representation, QGIS was struggling to render the map at different scales, sometimes failing to render after 30 minutes (Figure 14). From this experience, using low poly objects to create a 3D landscape within QGIS or ArcGIS Pro was not attempted.

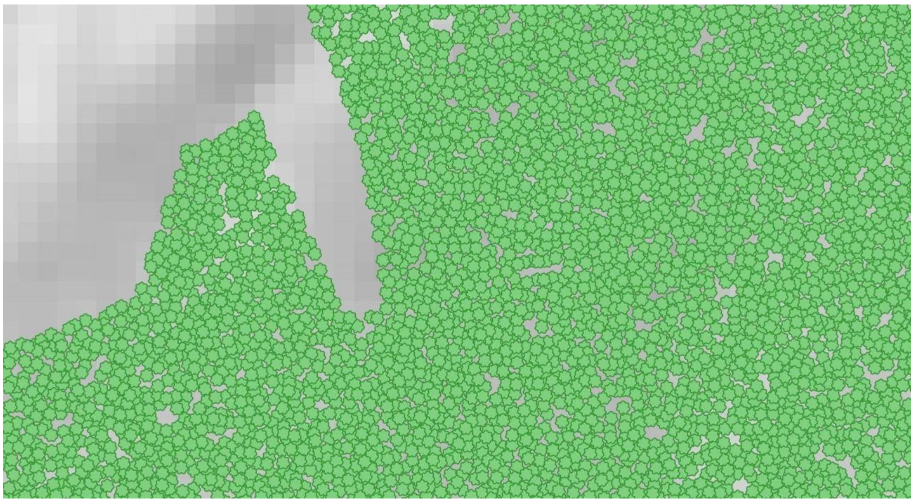

Figure 14: *Screenshot of random points prototype created in QGIS, with a tree top SVG at 1.5m real live scale to represent trees.*

The visualisation could potentially be turned into raster images and then tiled at different scales to improve rendering, but this would not allow for 3D rendering. Alternatively a Multipatch surface could be produced for the low poly objects, but it is unclear if this would work at the size of the study area. An additional alternative that was considered was visualising tree points as corridors along routes in the landscape, but QGIS and ArcGIS

Pro would make navigation along these difficult, and limit its usability for use with the public to increase engagement. The area of visualisation would have to be considerably smaller.

2.2 Blender Models

The software Blender 3.6 was chosen as it is widely used to generate 3D objects and runs without the need of a graphic card. There are many tutorials online to support their use for beginners, as well as community-based add-ons such as the BlenderGIS package which allows for the import of georeferenced images and shapefiles (Blender, 2020). Due to the unfamiliarity with the software (Blender) and uncertainty of the results an iterative development process was followed to create multiple prototypes, not all of which were saved as they were not meant as end products.

Users have a mental image of what a forest or landscape should look like, associating information with something familiar to them. However, native birch forests of Iceland (Figure 15) would be nothing like the large coniferous plantations many people would imagine, which is why the creation of tree models was considered an important step. There are numerous ways to create trees in Blender, the main considerations for this study where ease of use and free to use. Sapling Tree Gen (Blender, 2023), MTree (Herpin, 2020) and simple node extraction (King, 2021) were tested, but as the first tree prototypes were meant to potentially be imported into QGIS or ArcGIS Pro it had to be a low poly with few polygons and simple colour. To that end two trees where created by extruding nodes to form a trunk and branches, skin was applied and the object simplified before adding simple icospheres, following the tutorial by King (2021).

Figure 15: *Dense birch forests at Vaglaskógur. Pictures by Anthony Newton.*

Due to issues importing the DEM with Blender GIS (Blender, 2020) the first prototype was created on a simple surface representing simplified aspects of the diverse landscape such as glaciers, rivers, forests and wetlands. The next step was the creation of geometry nodes that randomly generate trees within a given area (vortex group) at random heights, following a tutorial by Geis (2023). As can be seen in Figure 16 trees are mostly limited to the green and brown areas, however there is one inside the river and some beyond the surface edge on either side. Although not fully successful, it proved that a forest out of trees at diverse size and rotation could be created within selected areas.

For the final model trees and shrub models were created using Sapling Tree Gen (Blender, 2023), which is a free add-on for creating realistic trees through the manip-

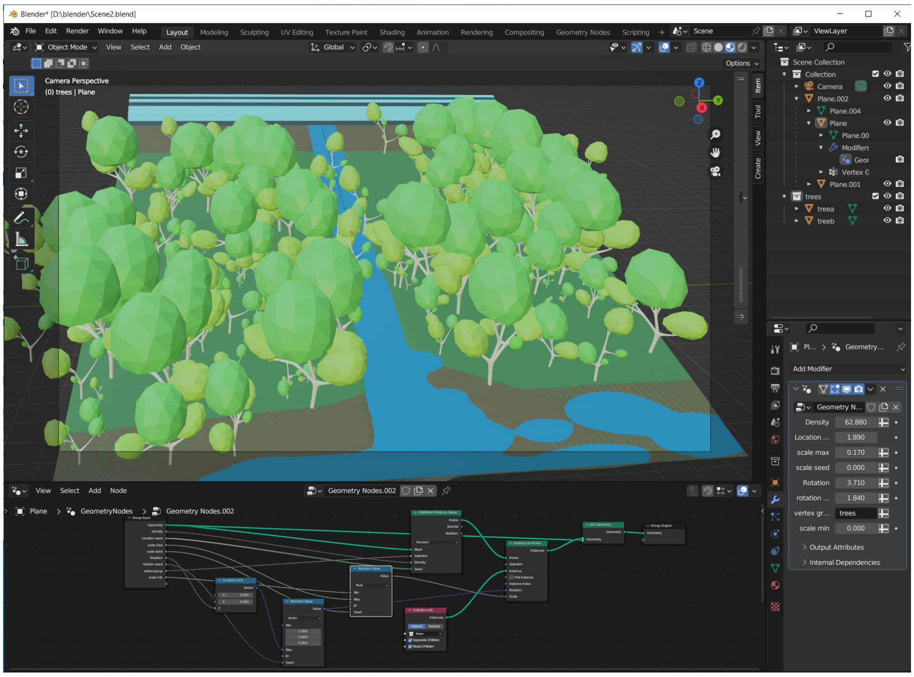

Figure 16: *Screenshot of the prototype of trees randomly generated across a surface.*

ulation of the geometry of pre-loaded randomly generated white birch trees (King, 2020). Textures for bark and leaves were added to create a more realistic look (Figure 17).

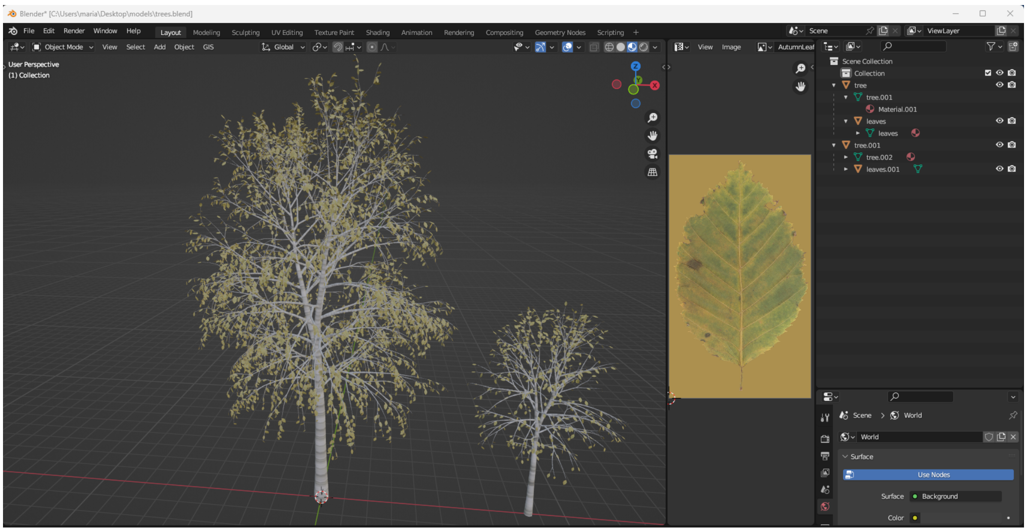

Figure 17: *Screenshot of the tree models created in Blender, with leaf texture image.*

Once the land cover model was completed (Maily, 2023a) the DEM of the area was imported into Blender 3.6 using Blender GIS (Blender, 2020). The area was too large to work with, making image overlay, particle system or geometry nodes unusable. The second attempt was done on a much smaller area, surrounding Thingvellir. On it a Google satellite image of 10 m resolution was displayed to have a more natural look (Figure 18). The image was downloaded using QuickMapServices (NextGIS, 2023) in QGIS. As can be seen in Figure 18 the trees in the center of the image (white circle) of sizes 12 m and 7 m are too small to even see. Even at this size creating geometry nodes failed, which was most likely due to the tree object size of 18 MB. For further attempts, an optimisation of the objects' mesh should be attempted in order to decrease the size of objects while preserving as much of a natural look as possible.

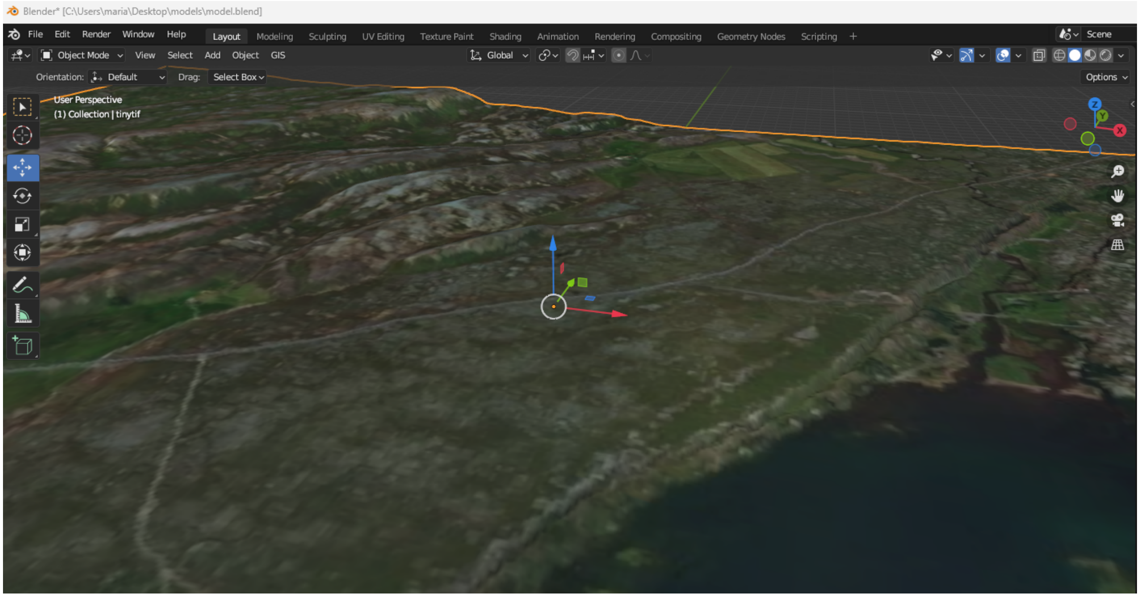

Figure 18: *Screenshot of the attempt of creating a 3D forest on a small DEM, with the google satellite image overlaid.*

2.3 Immersive Experience

Visualising large forests of unsettled pre-Landnám provided difficulties both for the technological aspects and the usability aspects. The scale is too large for people to truly create a mental image of the environment at the time. Therefore adding a road network presented an opportunity to carry this work forward, allowing for contextualisation of the environment by comparing the paths to modern day.

As Iceland has no native large animals that would have created paths through the dense forests and shrubs it is difficult to say how and where exactly they would have crossed the landscape without detailed models of the landscape. From historic texts and travel journals from the 19^{th}-century we can deduct that they would have avoided crossing rivers, dense forests, treacherous wetlands and lava fields (Connors, 2010; Morris, 1996). However, pre-19^{th}-century roads are considered a mere form of speech, signifying that one place could be reached from another, with a multitude of different paths the individuals could have taken depending on the season and weather (Shepherd, 1867; Connors, 2010). The earliest settlements were along the coastline, due to their rich natural resources, and only developed inland in later years of Landnám. Therefore, with the limited number of settlements in the study area it would be difficult to establish travel between just those settlements. However, as the parliament was created in A.D. 930, in a location that is considered an important cross road, the area would have seen an increase in regular traffic (Sanmark, 2022). Apart from regional social and economic travel, once a year settlers from all over the country would have travelled to the area. Much of the forest in the area would have had disappeared by this point, opening up the wide areas we see today (Vésteinsson et al., 2006).

With the loss of large vegetation, crossing large open spaces would have required landmark aids such as rivers, mountains and cairns to navigate from one place to another. Many of the early paths would not have left any evidence apart from mentions in sagas and remnants of place names. The only archaeological evidence of routes they travelled are cairns, however early cairns were probably made out of turf and most stone cairns can not accurately be dated but where probably constructed in the middle ages (Connors, 2010; Bolender and Aldred, 2013; Aldred and Lucas, 2018).

Nevertheless, as travel was determined by geography and climate, the main paths would not have changed much between A.D. 930 and the 19^{th} century, when the first solid roads where constructed (Connors, 2010). Large geographic features such as rivers, lakes and mountains that would have been used for navigation are still present, and are displayed on historic maps that depict old paths. As a source, Gunnlaugsson's map of 1844 was used as it is the first map that contains detailed information for such purpose (Section 1.2.3). However, as the map is inaccurate in the study area, some adjustments had to be made. Modern day water bodies and DEM were used to adjust the paths, where they overlapped features. Paths crossing mountains were an area of uncertainty, when possible general direction of modern *F* roads or hiking paths visible on maps were used to correct paths on steep slopes. Furthermore, Connors (2010) highlights errors in the map, that contradicts archaeological or historic evidence of roads. These were adjusted where there was strong evidence, otherwise this was not modified, as this was not necessary for this step of adjustment (Figure 19). The paths crossing lava field and particularly uneven ground south of lake Thingvallavatn are areas of uncertainty that will need further investigation. Lastly, the Öxará river was diverted before A.D. 930, due to time limitations this was not corrected, the consequences of this diversion are unknown.

These paths could be further improved by adjusting them to hiking and horse riding paths, or old paths known by locals. This step would allow for a comparison of modern-day paths visitors can travel with what it would have looked like during the settlement period. Of particular interest would be the paths along the north coast of the lake, in the Thingvellir National Park and possibly along the west coast, following the lake's outline (Figure 20).

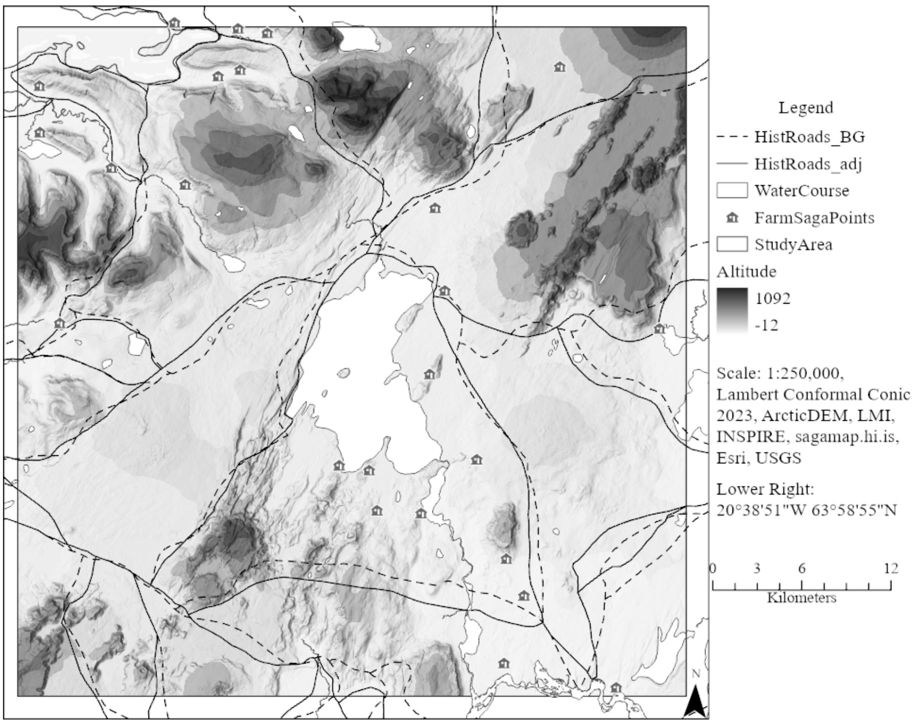

Figure 19: *Adjusted roads of the Gunnlaugsson's map.*

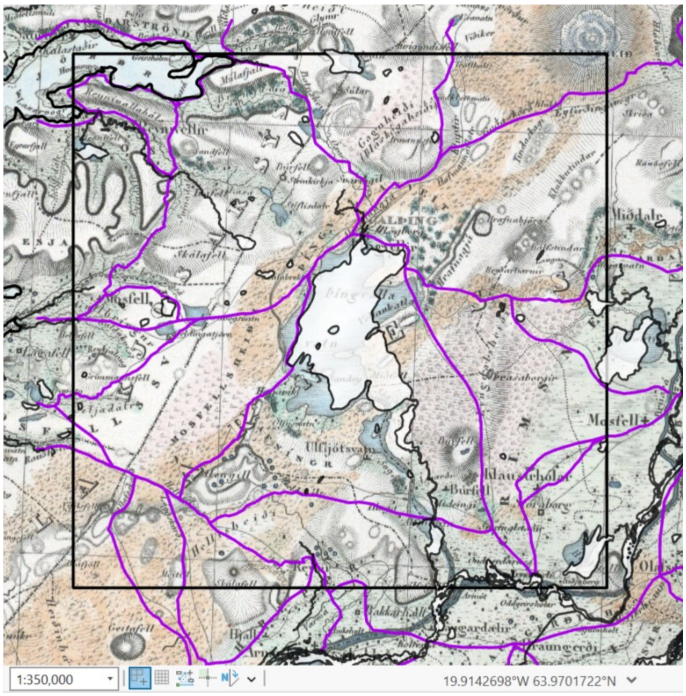

Figure 20: *Screenshot of the adjusted path network of the Gunnlaugsson's map, overlaid with water bodies.*

2.4 Future Work

While being a general-purpose modern 3D modelling software, Blender has shown many limitations for such as large landscape. As such, more advanced software, optimising the rendering of 3D landscapes, can prove to be more effective. Game engines like Unity or Unreal would be prime candidates, notably with the newly released ArcGIS Software Development Kits (SDK) for both engines that could be tested for further analysis. Furthermore, a game engine would allow for the creation of a fully immersive visualisation, allowing users to virtual walk through the landscape, observe diverse plants, hear sounds and experience the landscape at scale. Studies on their uses and capabilities have already demonstrated their potential (Herwig and Paar, 2002; Fritsch et al., 2004). The development of virtual simulation supports, such as the use of Augmented Reality (AR) on mobile devices or development of Mixed Reality (MR) headsets, could also prove to be a unique opportunity for engagement. However, any attempts should be iterative and improved through feedback from surveys of stakeholders and potential users.

As the Thingvellir Visitor Center has a 3D model of the area, a physical model of the pre-Landnám landscape could be added. Studies on physical representations of landscapes have demonstrated positive feedback from users (Anderson et al., 2018). As it would be within the actual landscape, direct comparison would have a positive impact on creating engagement.

The path information could be used to create and/or promote hiking paths with information on the past landscape, or an area where afforestation could be used to recreate such a landscape. Furthermore, an application similar to the Walking with Romans project in the Brecon Beacons National Park (Smith et al., 2018, 2022) could be created, with AR enriching the current landscape.

Lastly, time steps could be created to demonstrate the chronology of deforestation since settlement, however this would require a more detailed model and more detailed information on the settlements and deforestation in the area.

3 Project Conclusion

Initially the project set out to generate a digital twin on the Icelandic Landnám landscape in order to allow for the qualitative analysis of the resource network and routes used during settlement. This would have been supported by:

- Reviewing the environmental, archaeological and historic research and data available;
- Selecting a region of interest where the analysis of routes and network is of interest;
- Creating a model of the forest cover in the selected region;
- Creating a 3D model of the selected region incorporating both elevation and forest cover;
- Qualitatively evaluating the likely road and network development during settlement.

However constraints in the complexity of the project meant that this aim had to be revised. In the end, the project focused on the creation of land cover models to support afforestation efforts and public engagement in those efforts. The objectives were therefore revised to:

- Review the strength and weaknesses of existing pre-Landnám landscape recreations;
- Critically evaluate environmental datasets and their potential combined use in the creation of a land cover model;
- Re-imagine the pre-Landnám land cover by merging environmental, archaeological and historic data.

These objectives address:

RQ1 What are the strengths and limitations of pre-Landnám landscape recreations in the literature?

RQ2 How well can current-day environmental data sets, with the addition of archaeological data and historic documents, support a new model of the pre-Landnám landscape?

In addition, initial attempts at leveraging both traditional GIS and 3D modelling software were recorded and discussed to answer:

RQ3 What are the opportunities and limitations of traditional GIS and novel 3D applications for landscape visualisation?

This revision of aims happened after initial attempts at building prototype 3D models of the landscape. The iterative prototype development described in Section 2.2, was meant to build up the knowledge and technical skills required for such work. However, it soon became apparent that undertaking such a task, in addition to the other objectives set, would have been impractical in the scope and time limit of this dissertation project. Technological constraints, such as data storage and management, processing power, and tool novelty with little educational support, also proved to be limiting factors in the pursuit of this project.

Revising the aims has however proven to be successful in contributing to the research of land cover modelling, landscape recreation, and immersive visualisation. First, the methodology presents a novel classification approach to support land cover creation that represents the pre-Landnám landscape in more detail. Secondly, the investigation of possible data indicating possible vegetation habitats in the current-day model has allowed this research to highlight potential regions of interest for afforestation efforts. Finally, the research and attempts at creating immersive visualisations of the pre-Landnám landscape brought out many opportunities and considerations for public engagement, with applications in wider domains.

Such future work is detailed in Section 2.4. It suggests the use of game engines for the 3D visualisation, which could address the initial aim of creating a digital twin for the qualitative analysis of resource and road networks. Ultimately this type of analysis could bring forward insights into the development and survival of societies in difficult climates, a question holding more and more importance as the negative impacts of climate change are becoming irreversible.

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