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Geographical Information Management and Applications

Exploring 3D visualisation of vegetation

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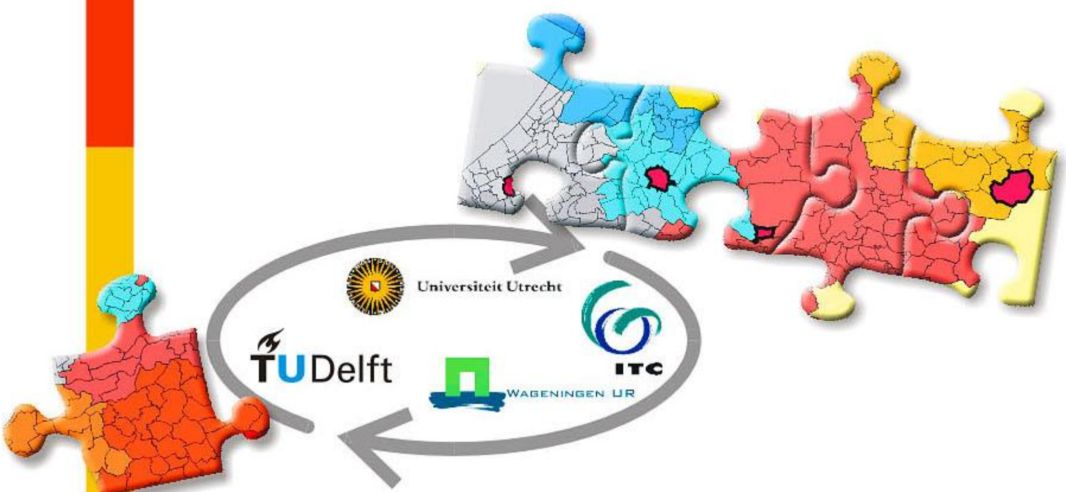

Exploring 3D visualisation of vegetation

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Abstract

3D visualisation of vegetation change can communicate for instance the loss of rare plant species, vegetation stress or vegetation risks in order to raise awareness. 3D visualisation might also be helpful in the nature management process, by visualising the effects of certain decisions, such as removing biomass from a vegetation area. In order to make a 3D visualisation of a vegetation model, it is necessary that this model has a map as output together with more information which describes the composition of this vegetation. These will serve as the input for distribution modelling of the individual plant species. 3D models of the plants can be placed at the point distribution which is created by this distribution tool. To get these 3D models of the plants, the plants which contribute to the grain, colour and structure of the vegetation type will have to be selected and 3D modelled. This point distribution of the plants and the 3D models can be brought together in a 3D simulation, together with a DEM and an aerial photo to model height and to give the substrate a natural colour

There are several models for vegetation modelling, plant distribution modelling and 3D plant modelling. The vegetation modelling is done using vegetation mapping models or vegetation succession models. The mapping can be done using geostatistical interpolation, generalized linear networks, artificial neural networks and classification trees. These models result in a map, and in order to be used as input for the plant distribution tool, a description of the abundance of each plant species within the vegetation types is necessary. However, when the species abundance is described using the Braun-Blanquet scales as a cover percentage, it is not possible to use it as input for a computer generated distribution, because this requires the plants per square meter as an input. A conversion is possible, but requires accurate modelled 3D plant models. The vegetation succession modelling models the transition from the one vegetation type to another vegetation type. This change is driven by changing circumstances for the plants and the output as biomass is calculated for five different layers in the vegetation. In order to model this layered output correctly, it is necessary that the 3D plant models give a correct representation of the biomass of the plants and it therefore requires accurate 3D growth models of the plant species.

There methodologies for creating a plant distribution vary a lot in complexity: the complex Agent Based Models and Cellular Automata can model competition for resources and dispersion, but also require a lot of research, calibration and validation. A simple computer generated distribution on the other side does only require the number of plants per square meter per vegetation type as input.

The 3D plant models can be divided into two types: the accurate models and the sketch based models. Accurate modelling techniques are AMAP and L-systems and it requires scientific measurements of the plants growth, size and shape to model a plant in 3D and the modelling needs to be calibrated and validated. These accurate 3D models are necessary to model vegetation succession or to make a conversion from a cover percentage to the number of plants per square metre. The accurate modelling techniques can also be used sketch based, but for instance Xfrog works faster if a plant has to be 3D modelled. Photographs from different angles of the plant can serve as the input for the sketch based modelling process.

This research has shown that 3D visualising a vegetation map with a computer generated distribution and sketch based 3D plant models is possible. However, vegetation maps with the plant species abundance described as cover percentage are unsuitable for 3D visualisation, unless an easy method is developed to convert this percentage to the number of plants per square meter.

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1 Introduction

The development of 3D visualisation of geographic data can make a better interpretation of the data possible. Old paper maps can only indicate what is located where and the viewer has to visualise for themselves how the situation shown on the map might look in reality. 3D visualisation however has already taken care of this transition from 2D to 3D. This has two major advantages: the viewers no longer have to create the 3D picture of the area themselves and all the persons viewing the 3D visualisation share the same image of the area (Borsboom-van Beurden, 2006, p87). These 3D visualisations can be used for various goals. Google Earth for example has the buildings in Amsterdam in simple 3D shapes and users can walk or fly through the landscape of Amsterdam and see all the buildings (Kromwijk, 2007). It is also possible to visualise the results from planning processes or geographic decision support systems in 3D. The involved parties can view the new plans in 3D and see where new buildings and also nature will be located. For example CommunityViz, an extension of ArcGIS is capable of doing this (Placeways, 2009). These are examples of applications in which the 3D visualisation already has been taken care of and whose 3D visualisation improves the interpretation of the area or the plans. However, other models and applications exist which also model changes over areas, but which are not visualised in 3D yet. This is the case with the SMART2-SUMO2 model combination for vegetation succession modelling or with the vegetation mapping models. The output of these models can be the vegetation structure, which is the composition of vegetation layers (Wamelink et al., 2009), or the vegetation texture, which is the different types of vegetation and the species of which the vegetation is composed.

3D visualisation of vegetation and changes in the vegetation caused by nature management or external influences as modelled by these vegetation models can help nature managers in understanding the vegetation changes caused by certain maintenance actions or external influences. External influences could be for instance climate change or sea level rising. The following paragraph will go into detail what is necessary to create a 3D visualisation of vegetation change models. The last paragraph will give a brief introduction to the case study which will be used in this research.

1.1 Necessary models for a 3D visualisation

Vegetation can be defined as an area with a distribution of a mixture of plant species specific for this vegetation type and which mixture is homogeneous over the whole area. A 3D visualisation of vegetation will therefore visualise these plants and distribution by visualising each individual plant on the location specified in the distribution of the vegetation type. It is therefore necessary to have 3D models of all plant species present in the vegetation type which will be visualised in 3D and a distribution of all plants in the vegetation which contains the X and Y coordinates of all plants. Figure 3 shows in a schematic overview how the vegetation modelling, plant distribution modelling and 3D plant modelling are linked together to come to a

3D visualisation of the vegetation model. This schematic overview is based upon research into 3D visualisation of land use models and maps by Van Lammeren et al (2005, p137). Their methodology is shown in figures 1 and 2. The input map for a 3D visualisation of land use is a raster land use map. This input map is combined with 3D tiles each representing a land use type. These 3D tiles are placed together according to the land use map (Figure 1) and form in this way a 3D visualisation of the land use map (Figure 2). The 3D visualisation of vegetation will also bring together the map and the 3D models. The difference with the 3D land use modelling is that the distribution of the tiles in the land use modelling is done via the input map, whereas the 3D vegetation visualisation will need an intermediate step to make the distribution for the 3D models of the individual plant species. Furthermore, the vegetation mapping process uses other geographic data as input for the mapping process and this geographic data is therefore placed before the vegetation modelling tool.

The following two paragraphs will give a brief introduction into distribution models and 3D plant models.

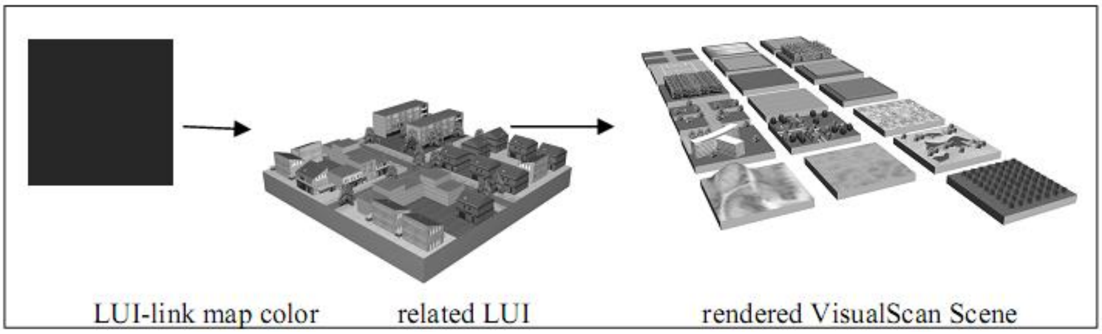


Figure 1: From 2D data into 3D visualisation: subsequently phases (Lammeren, 2005, p138)

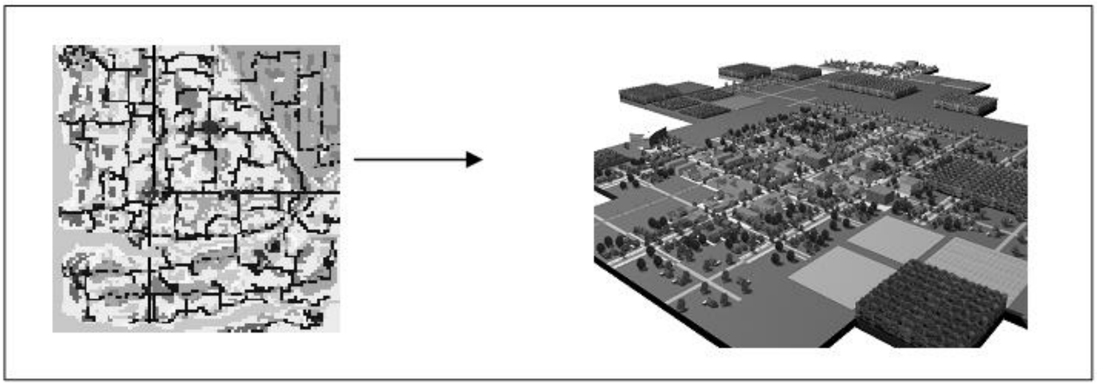


Figure 2: From 2D raster data into a VisualScan Scene (Lammeren, 2005, p138)

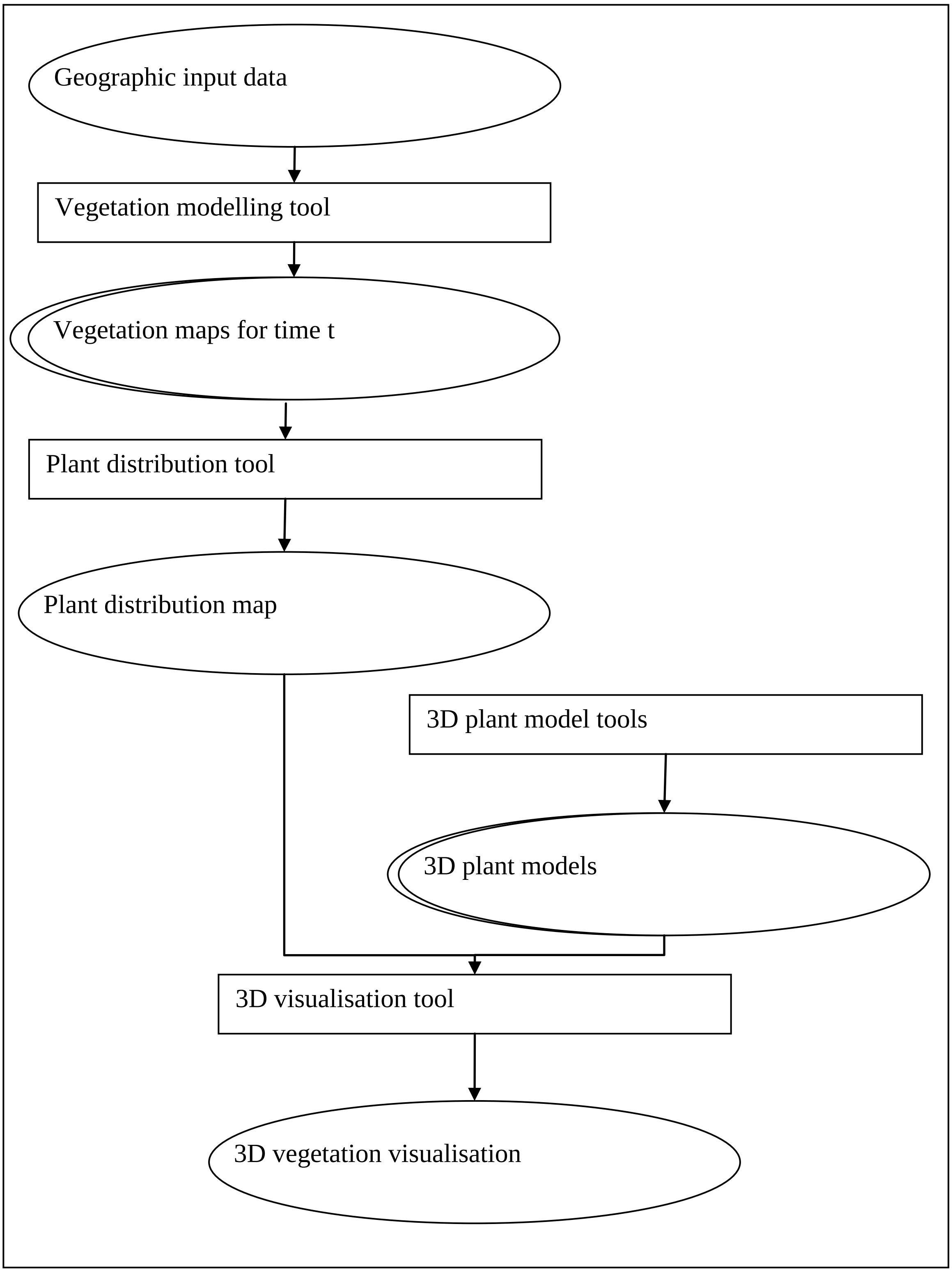


Figure 3: schematic overview of the 3D vegetation visualisation process

1.2 Distribution models

The difference between decision support systems, whose results are nowadays often visualised in 3D and the modelling of vegetation is the fact that for decision support systems, the future situation can be designed by a planner, while for vegetation modelling, no planning or designing takes can place, because the situation already present must be described. Unless of course landscape designing takes place and plants or seeds are planted by humans. It is of course possible to go into the field and to record all locations of all plants, but this process is very time consuming and does not allow for future predictions. Therefore, a model is needed which describes how the individual plants are distributed over an area.

To put it in a different way: the scale at which individual plants can be mapped is larger compared to the scale of the input maps about the abiotic components of the soil or the maps about the different vegetation types. It is possible that more plants grow in a specific area having certain abiotic component characteristics. Where and how much of the plants, which are suitable of growing in that area, should be located exactly is unknown, because the input maps only give information which plants are not constrained to grow there. To create a small scale dataset from large scale data is easy, because it only involves aggregating the large scale data. However, if a large scale dataset has to be created from a small scale dataset, more information has to be put in the model used in this process for this to overcome the transition from small scale to large scale. A plant distribution model can make a transition from small scale to large scale by using extra information about how plants are distributed in reality. A proper distribution model is therefore needed which is able to distribute the plants in a natural way.

A possible solution to model the distribution of all possible plants is to use an agent based model. The agent based approach makes a visualisation of all individual plants possible. By assigning simple rules to agents, a complex system such as a landscape can be created trough interacting agents. The model will be self-organizing and therefore the only thing that has to be done is to define and implement the rules into the model. Furthermore, the agents can react or interact with the environment, for example the soil. For proper plant life modelling, knowledge is necessary about the life cycle, the preferences, the growth type, the tolerance, the reproductive life cycle and the germination conditions of all plants. Furthermore, there are algorithms needed based on the following biological principles: seasonal effects on reproduction, seed dispersion, seed dormancy before germinating, plant adaptation, upper, lower and ideal values and plants competition for sunlight space and nutrients (Ch'ng, 2009). Therefore a distribution model will have agents with certain characteristics about their life cycle, preferences etc. and with these characteristics, the agents interact via the biological algorithms. This will result in a (point) distribution of different agents in an area with certain abiotic characteristics or vegetation type which can be visualised using 3D visualisation techniques. Another possible solution could be to model the plant distribution with cellular automata using a very fine grid in which each cell contains one specific plant. The same parameters and algorithms can be used to model competition, seed dispersion, etc.

It is also possible not to use a distribution model and to let the software make the distribution. Of course, this distribution cannot be based upon the interaction that takes place between plants and between plants and the soil. The only thing one has to do is to define the cover which a specific plant type has and the software will spread this plant over the area and the software will put the plants into the specified area (Roehricht, 2005).

1.3 3 Dimensional plant growth models

The methods to visualise plants and trees in 3D have been listed by Muhar (2001). He distinguishes between three modelling methods: Simple 3D-symbols, 2D-images in 3D faces and automatic generation of plant structures, such as stems and leaves. The simple spheres visualise trees drawing by cones and spheres. However, the simple 3D symbols are used on trees and shrubs to visualise them roughly and cannot visualise the real plant structure and simple 3D-symbols are therefore not very suitable to use as a visualisation method for small vegetation. 2D-images in 3D faces are also less suitable, because the small shrubs and herbs will mostly be seen from the top and a billboard visualisation does not work very well from that angle. It would require many photographs of all plants and in all growth stages to use as textures for the 3D faces. The advantage of this method will be an easy interpretation of the impact of circumstances and competition of the viewer (Muhar, 2001). The automatic generation of plant structures can be done using fractal structures, L-systems, the AMAP-system and the TREE-system. The TREE-system is not suitable for this research, because it can only be used for automatic generation of trees. The AMAP-system can be more suitable, because it has been developed to simulate crop growth and it has also been used to visualise the development of open space. However, the parameters to generate plants will have to be collected and inserted for each plant. The generation of plants using fractal construction can be done, because biological structures follow the principles of self-similarity. However, the downside of the fractal construction method is that the amount of realism achievable is not very high. The L-systems grammar has been developed for about 20 years. It describes the growth of plants in a mathematical way. L-grammar can simulate stems, branches and leaves. This L-grammar can be used to create 3D plants in software such as L-Studio or Vlab (Muhar, 2001). However, this overview of Muhar does not cover all 3D modelling techniques. According to Pradal et al. the automatic generation of plant structures falls within the modelling style of accuracy, conciseness and transparency. And in their work another modelling style has been recognized with the following characteristics: interactivity, intuitive, with less biological expertise and more sketch based. These characteristics results in 3D models of plants with a high level of detail, but which are not based upon growth processes derived from reality. This kind of models can be created with, for example, Xfrog (Pradal et al., 2009).

Therefore, four different categories can be discerned for 3D modelling of plants: simple 3D models, 2D-images in 3D faces, complex 3D symbols based upon automatic generation of plant structures and complex 3D symbols based upon 3D drawing techniques.

1.4 Ameland case study

The 3D visualisation of vegetation change will be applied in a case study. This case study will be about vegetation change at the island of Ameland. The island of Ameland in the north of the Netherlands is an island composed of dunes and an important island for nature. Due to drilling for gas, the eastern part of the island has subsided allowing sea water to enter and to change the abiotic circumstances. These changing abiotic circumstances in turn affect the presence of various plant species in that area and the spread and the type of species therefore have changed (Slim, 2005). Visualisation of these changes and predictions for further change in 3D can therefore help policy makers and other involved persons or parties in understanding what effects the subsidence has on the nature in that area. The changes in the locations for the vegetation types present in the research area have been modelled with a vegetation mapping model. Furthermore, it should be possible to create scenarios for this area with variations in (relative) sea-level rise and to 3D visualise these scenarios.

1.5 Problem description

3D visualisation of the vegetation change caused by nature management or external changes can help in the nature management process. However, if the effects of a nature management decision or external change on the vegetation structure or vegetation texture have to be 3D visualised, it is necessary to combine dynamic vegetation prediction models with 3D visualisation techniques. These techniques however seem not yet applicable.

1.6 Research objectives and research questions

The main research objective is:

3D Visualisation of dynamic vegetation prediction models which support nature maintenance modelling.

The general research question is:

What are the possibilities to 3D visualise dynamic vegetation prediction model outcomes using 3D plant models and a plant distribution model?

The general research question will be researched with the following sub-questions:

- What kinds of dynamic vegetation prediction models are being used to predict vegetation and for what objectives are these models being used?
- Which models are there to model plant distribution in an area?
- Which models are available to model plant growth in 3D?
- How should the vegetation models and the 3D visualisation techniques technically be combined to make a 3D visualisation of the vegetation model?
- Do the 3D visualisation results of the dynamic vegetation model support the nature maintenance process?

1.7 Methodology

The methodology describes how this research will be set up. A schematic overview of the methodology together with the deliverables of each step can be found in Figure 4 on the next page.

1.7.1 Research introduction and research proposal

The research starts with writing the research introduction and the research problem. These two can be found in this research proposal. The research introduction and research proposal will together make up the first chapter of this research.

1.7.2 Literature research

The next step will be a literature research into vegetation prediction models, plant distribution models and 3D growth models of plants. More knowledge is needed about vegetation prediction models to make a good connection between the vegetation prediction model and the distribution model and 3D plant models. There are various models for plant distribution and all the model possibilities, including Agent Based Modelling, Cellular Automata and computer generated distributions, will be in the literature research.

The 3D growth models research will be based upon the overview article of Muhar (2001), who has given a good overview of the techniques available at the time of writing his article. But because computer graphics and modelling techniques evolve, more research is needed to get the latest technology, software and techniques in this field. The research into 3D plant growth models will be the answer to the third research question

It is also necessary to study the possible problems which may be encountered when vector or raster vegetation maps are used as an input map for the 3D visualisation process, because the vegetation map has not been created for this purpose and may for this reason pose some limitations on the 3D visualisation or cause errors in the 3D visualisation. The possible problems which will result from this study will partially answer to the fourth research question. The application of the models in a case study will complete the answer to the fourth research question.

1.7.3 Case study

The application of the distribution model and the 3D growth models will be done in a case study. Case studies can be applied in research when the subject needs to be researched with all aspects together and in relation. It makes it possible to show the different aspects of the case within the larger context of the 3D visualisation. Problems which might not occur on themselves might occur when such an aspect is applied in a larger case due to the relation with other aspects (Baarda, 2005 p112-117).

The case itself has already been introduced in the introduction as well as the 3D vegetation visualisation process. To realise the 3D visualisation, four tools have to be used: the vegetation modelling tool, the plant distribution tool, the 3D plant modelling tool and the 3D visualisation tool. Three of these four tools use a model to produce the results and using models will require some choices and also some elaboration on how these models will be used in this research. Therefore, the choices which will have to be made will be listed here. The vegetation mapping model which has been used to model the vegetation at Ameland will be used as an input model which will be 3D visualised. In order to simulate vegetation change, this model will be run again with an assumed further subsidence of the soil. This will result in a relative see level rising and will therefore result in a vegetation change. The resulting vegetation maps will then be modelled in 3D with the distribution model, 3D plant models and suitable software. The choices for the distribution model and the 3D plant model will have to be based upon the capabilities of the. Furthermore, it is necessary to decide whether it is feasible to include an advanced distribution models into this research. It would be more scientific to include an advanced distribution model, but if such a model takes too much time for creation, calibration and validation, it would be better to use a computer generated plant distribution. It is also necessary to check which of the 3D growth models are feasible to use. Some models look very promising in terms of realism, but creating 3D plants for the Ameland research area using these models might require too much time when these advanced models are used on all plants. Therefore, only a selection of the most abundant plants will be visualised when these advanced methods are used and if a modelling technique is too difficult, it will be left out. The next step will be to gather the input information for the distribution model, when a realistic one is chosen and for the 3D plant growth model and to convert it into the parameters required for the models. Then, all the parameters and the biological algorithms have to be put into the models. When all parameters and algorithms have been put into the models, the 3D visualisation will be created. This will result in a number of 3D landscapes at different time steps or in one landscape which can change over time within the 3D visualisation.

1.7.4 Expert test

The 3D visualisation will be tested with some experts. These experts will be people working in nature management or who are involved in the research area of the Ameland case study. To test the visualisation, a number of questions will have to be prepared which will cover all the relevant aspects of the 3D visualisation. The relevant aspects will be based on literature. This questionnaire will therefore be a kind of a structured interview with fixed questions (Baarda, 2005, p235). The 3D visualisation demonstration will be held in a session with these experts and this makes it possible to discuss the results and ask evaluation questions directly. This will be a group conversation, which is very suitable for exchanging ideas and generating new ideas (Baarda, 2005, p238). If this is not possible, a demo will be prepared and distributed via the internet together with the prepared questions. The answers to the questions will be used to rate the successfulness on each aspect on. These scores with an argumentation for this score should give partially answer to the last sub-research question together with the results from the discussion. The answer to the last sub-research question will be completed with the results achieved in the case study.

The expert test is in fact a research on its own, because it will require a small literature study and also research question 5 can be divided into multiple sub questions. It is however necessary to validate the results from the case study in order to answer the main research question and it therefore chosen to include this research into the main research in order to validate the results from the case study.

1.7.5 Finishing of the thesis

The literature review, 3D visualisation of the case study and the experts view on this will result in an answer to the general research question, which will be the conclusion of this master thesis. This conclusion will be followed by recommendations for further research.

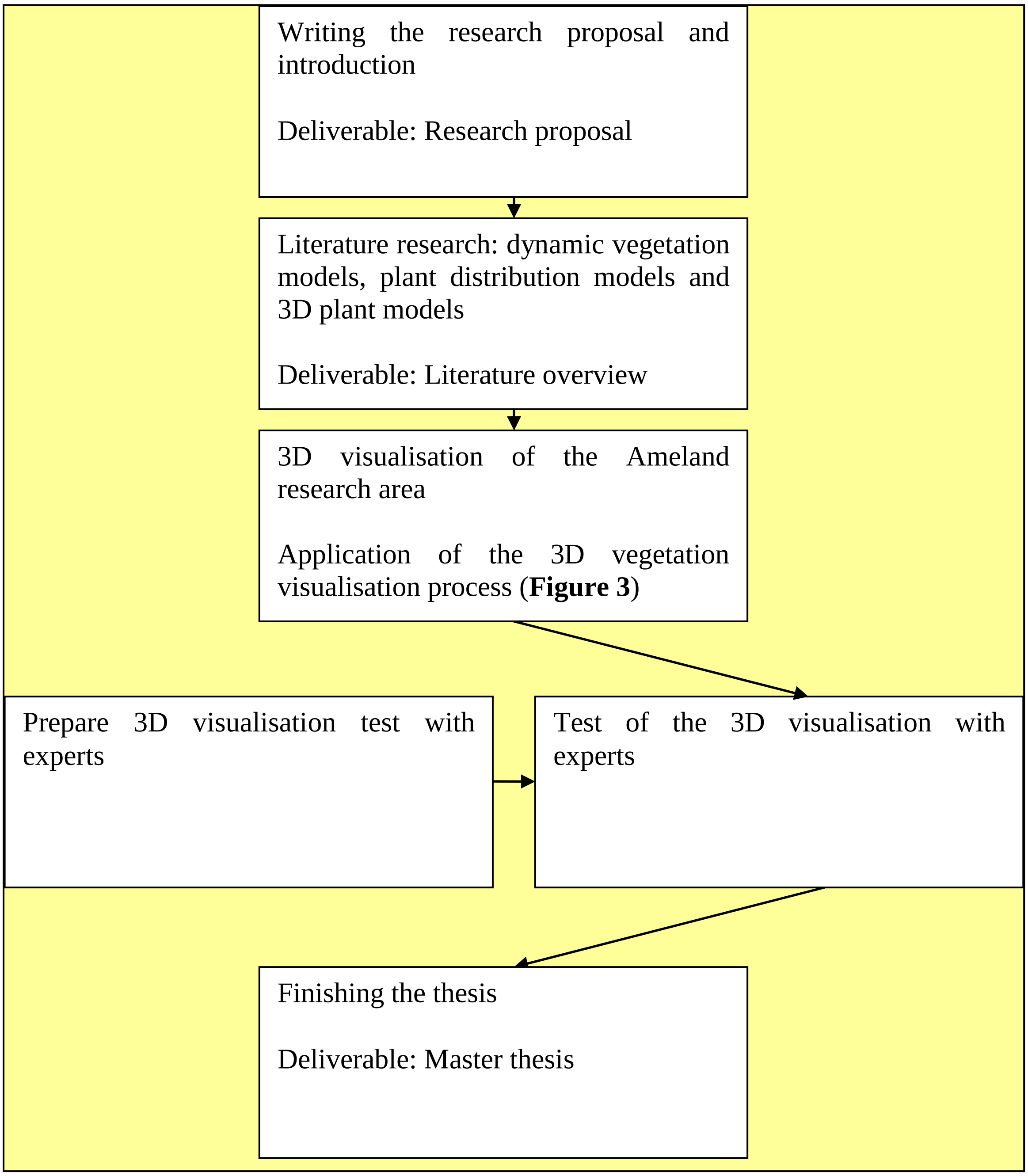


Figure 4: Schematic overview of the methodology

1.8 Scope

The aim of this research is to research the possible model combinations to create a 3D visualisation of vegetation models. All possible models will be described in the literature study, but it is out of scope to test all these models in the case study. Only one vegetation model will be used in the case study. The use of distribution models will also be limited to one. The modelling techniques used to make the 3D plants will be limited to two, because more than one 3D plant model will be created and this makes it possible to use multiple modelling techniques, but the limitation here is that learning a modelling technique requires time, which is limited. It is therefore chosen to use two modelling techniques in order to have more time to model more plants.

In is not within scope to spend a large portion of time on one of the models in the case study. The use of distribution models which costs a lot of time to create is therefore out of scope. For the same reason, it is out of scope to create a large number of 3D plant models.

It is not within scope to do an expert test with a large number of experts from various organisations. It would require a lot of effort to get a large group of experts and it would take too much time to process all the results from a large group of experts. The expert test will therefore be done with a small number of experts from WUR. It is also not within scope to do an extensive literature research for evaluation criteria for the 3D visualisation which can be used in the expert test.

The aim of this research is to carry out the whole process of 3D vegetation visualisation and, by doing this, to find out which problems can be encountered in the 3D vegetation visualisation process.

1.9 The structure of this thesis

This thesis will start with the results from the literature research. Chapter 2 contains the results for the vegetation models, chapter 3 the results for the plant distribution models and chapter 4 the results from the literature research for the 3D plant modelling techniques. Chapter 5 contains the results on the data quality aspects.

Then, the case study will follow. This case study is composed of several parts, the first paragraph will present the used geostatistical vegetation model and the output results from it as well as the scenarios created with it, the second paragraph will discuss how the 3D plant models were created for this case study. The third paragraph of this chapter will then discuss how the distribution of all individual plants for this case study was created and how these models were linked together to create the 3D visualisation and the fourth paragraph will show 3D visualisation results.

This 3D visualisation will be presented to the experts and the test setup, the questionnaire and the results from this will be in chapter 7. The achieved results of this thesis will be discussed in chapter 8 and the conclusion will be drawn in chapter 9 together with recommendations for further research.

2 Vegetation modelling

There are different methods to model vegetation and the outcomes of these models are used for different goals. The following paragraphs will discuss vegetation mapping modelling methods and the vegetation succession modelling. The last paragraph will discuss how 3D visualisation can be linked to these methods and how it can help in fulfilling or extend the goals of these methods.

2.1 Vegetation mapping models

Vegetation maps show the vegetation type distribution and can be helpful in the interpretation of vegetation change or landscape change. Comparing vegetation maps of different times makes it also possible to see how the vegetation has changed and where it has changed. Furthermore, it is possible to use a hypothesized influence by changing one of the input variables to test the sensitivity of a vegetation distribution to external change (Cairns, 2001). There are several methods to create these vegetation maps: geostatistical interpolation, generalized linear regression, artificial neural networks and classification trees.

To make the vegetation maps using geostatistical interpolation, the vegetation type is determined at a large number of points in a circle around this point. The found plant species are classified into a vegetation type and this classification results in a vegetation type at a specific point. In order to determine the vegetation types in all areas which are not measured geostatistical interpolation will have to be used (Slim, 2005). Possible interpolation techniques are trend surfaces, regression models, thiessen polygons, linear interpolation, inverse distance weighting and kriging. All methods except for kriging are deterministic and only good for a quick interpolation. Kriging however is a stochastic method and a good method for interpolation (Burrough & McDonnell, 1998, p147-159). Figure 5 shows the resulting maps from the geostatistical interpolation process created from samples which are taken at two different moments in time. These maps make it very easy see the changes through time. If universal indicator kriging is used, it is possible to create scenarios for vegetation change by altering the maps used as indicator values in the kriging process. Linear regression is used to determine how the indicator values relate to the vegetation types. If for each time step one or more maps are available with indicator values, it is possible to generate vegetation maps for each time step with the vegetation distribution. However, this is under the assumption that every other aspect determining the vegetation type remains the same.

It is also possible to make predictive vegetation maps using generalized linear models without the kriging process. A generalized linear model gives a probability of a specific vegetation type given a specific set of environmental circumstances at a location. The generalized linear model has to be created for each vegetation type. This will result in probability map for each vegetation type. The last step of this method involves the classification of all locations by assigning the vegetation type with the highest probability to that location (Cairns, 2001).

Another method to make predictive vegetation maps is to use artificial neural networks. Artificial neural networks consist of an input layer, a hidden layer and an output layer. The nodes in the hidden layer calculate and transfer values between the input layer and the output layer (Figure 6). It has a back-propagation learning algorithm to make corrections in the internal structure. The model has to be trained based on the amount of error in the output layer. The training of an ANN is done using a training data set (Cairns, 2001).

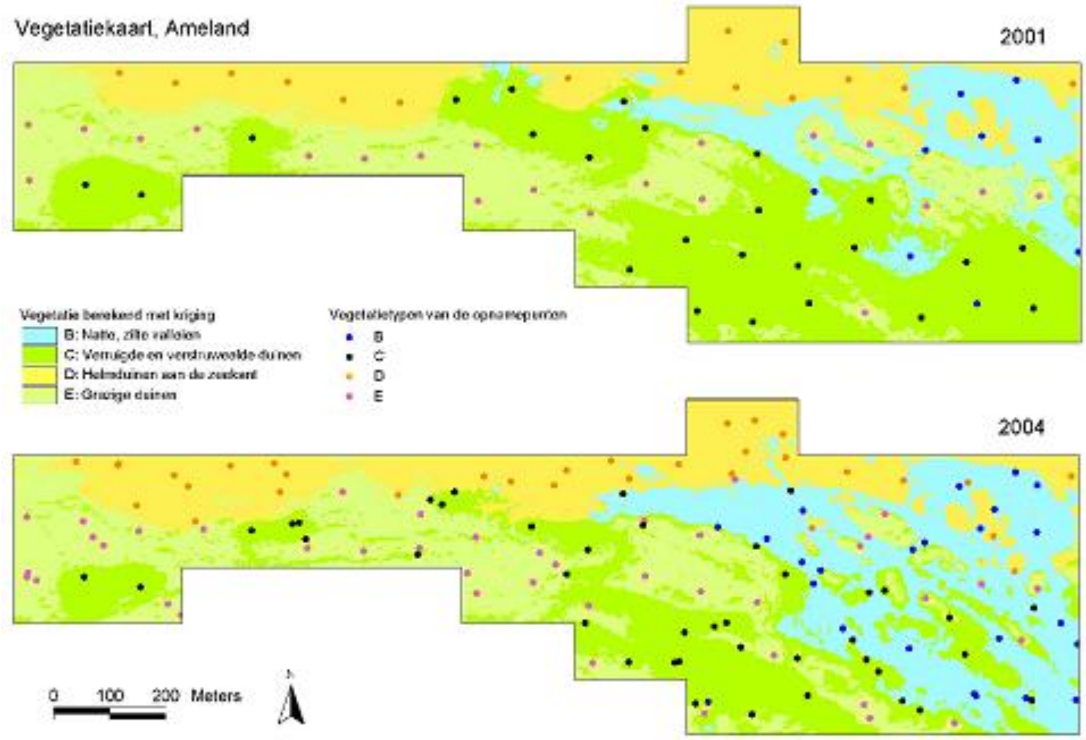


Figure 5: Vegetation map created with geostatistical interpolation (Slim et al, 2005)

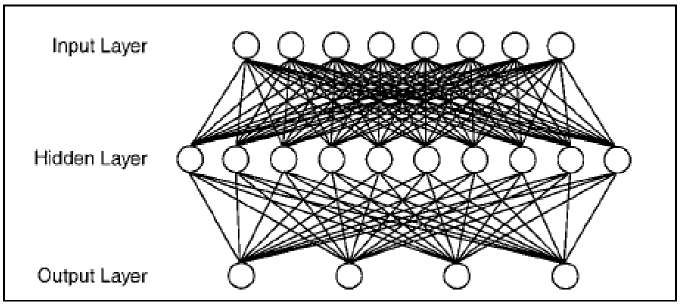


Figure 6: The structure of an Artificial Neural Network (Cairns, 2001)

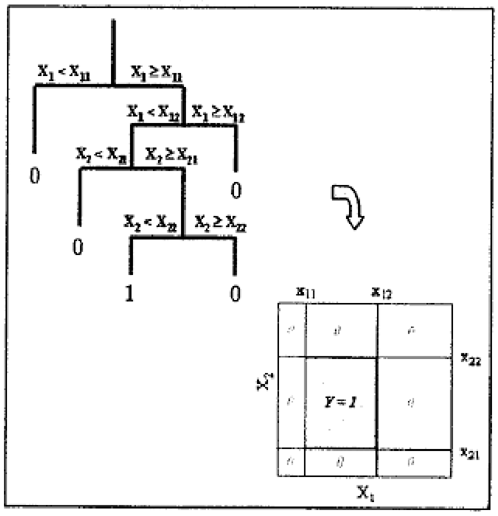


Figure 7: An example of a classification tree (Guisan & Zimmermann, 2000).

Classification trees consist of rules in the form of a tree. Each rule is a split in the tree and each rule aims at reducing deviation. The process of splitting stops when the data is homogeneous or when there are too few observations. The rules for a split can be derived from knowledge from literature and laboratory tests or directly from the observations using the CART-algorithm (Guisan & Zimmermann, 2000).

2.2 Vegetation succession modelling

The SUMO (SUccession MOdel) model has been developed to model vegetation succession. Vegetation succession is the change from one vegetation type to another vegetation type. This change is driven by changing circumstances which affect the growth conditions of plants such as atmospheric deposition of nitrogen, management of the vegetation and changes in soil circumstances (pH, groundwater levels). Soil processes are regarded as the most important processes which regulate vegetation succession. In order to model the soil circumstances, SUMO has been developed as an extension of the SMART2 model (Wamelink et al., 2009). This model is meant to model soil acidification and nutrient cycling, including the N atmospheric decomposition (Mol-Dijkstra, 2001). SUMO extends SMART2 therefore with the vegetation management aspect, which will be discussed later on this paragraph. The outcome of the SUMO model is the biomass which is present in an area. This biomass is computed for five layers in the vegetation: herbs and grasses, dwarf shrubs, shrubs, pioneer trees, and climax trees. For the first three layers the biomass is computed for all species together, while for the trees, the biomass is computed for twelve specific tree species. For each functional type, the biomass of the root, stem and leaves are computed. The growth this biomass is reduced by the amount of nitrogen available and the available sunlight. Furthermore, the dead biomass containing nitrogen is returns to the soil via the SMART2 model.

SMART2/SUMO can be extended to model the plants present in the vegetation using MOVE. MOVE can model the chance of occurrence of about 900 plant species using the SMART2/SUMO model output as input.

The management of vegetation influences the amount of nutrients in the vegetation. This in turn affects the circumstances which regulate the succession of vegetation and it is therefore possible to manage vegetation succession with vegetation management. There are four types of management: mowing, turf stripping, cutting and grazing. Mowing mainly reduces the amount of biomass in the grass and herbs layer. Turf stripping reduces the biomass of all layers and takes away the humus layer, which in turn lowers the amount of nutrients in the soil. Cutting involves the thinning of a forest. Some trees are cut down or have branches removed from them and this wood or biomass is taken out of the system. Grazing can be simulated for 15 grazing species. They eat the biomass and return nutrients through their manure (Wamelink et al., 2009). The SMART2 model can be computed on a grid with cells of $250m^2$ (Mol-Dijkstra, 2001) and this raster map can be used to make the distribution of the plants.

2.3 What should be 3D visualised of these models?

The vegetation mapping models do have as objectives to map the vegetation and to make vegetation change visible by making maps at different times. A 3D visualisation of these vegetation maps would first just be the vegetation types at their locations. The species which belong to a vegetation type will have to be distributed over the area which the vegetation type covers and 3D models of the plants which are found within these vegetation types have to be visualised with this distribution. The change can be 3D visualised by making 3D visualisations for all time steps and by offering the possibility to the user to switch the time steps. Switching between 3D visualisations can make it possible to see how changes in the input maps change how the landscape looks like. 3D visualisation might therefore add another use for predictive vegetation models.

The SMART2/SUMO model combination already has some 3 dimensionality in it, because it is computed on a grid and it models the biomass in five different height levels. It is not capable of simulating the plant species that grow within the vegetation type, but MOVE could provide this. If a 3D visualisation of the SMART2/SUMO should be made, it should be an extension by having the same goal of modelling vegetation succession. The 3D visualisation should 3D visualise the changes in vegetation type over time and could visualise scenarios. 3D visualisation of scenarios could make a better understanding possible of how vegetation management will turn out in the future. Furthermore, the 3D visualisation should also give a proper representation of the amount of biomass in each layer (herbs and grasses, dwarf shrubs, shrubs, pioneer trees, and climax trees). The 3D models of the plants should therefore have a growth function in it to cope with biomass differences and plant age. The result should be 3D visualisation which clearly visualises vegetation succession and the amount of biomass.

The use of 3D visualisation showing how the landscape can change can be targeted towards lay people to raise awareness about certain changes, such as climate change. According to Sheppard (Sheppard, 2005) vegetation succession, the loss of rare plant species, vegetation stress and vegetation risks can only be communicated by 3D visualisation because these processes are too subtle or due to slow working processes, invisible in reality. Figure 8 shows how this can be done with two forest management alternatives showing the situation many years after the plan has been implemented.

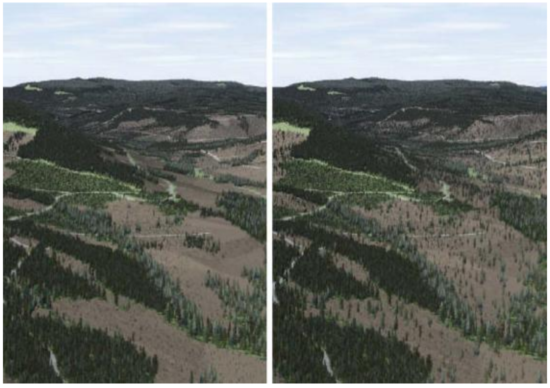


Figure 8: 3D visualisation of forest management alternatives (Sheppard, 2005)

2.4 Conclusions on vegetation modelling

There are two major types of vegetation modelling: the vegetation mapping models and the vegetation succession models. The mapping can be realised by taking field measurements and kriging, generalized linear models, artificial neural networks and classification trees. All these methods will result in a map with differing vegetation areas. 3D visualisation of a vegetation map will therefore make these vegetation types visible in 3D. The vegetation succession model calculates the biomass for five layers of vegetation. Changes in soil acidity and N decomposition will lead to changes in the biomass and to succession of the vegetation. 3D visualising a succession model will have to take into account the modelled biomass via 3D plant growth models and it will need a good distribution of all the plants and the trees.

3 Plant distribution models

A distribution of all plants over an area having a specific vegetation type can be generated with agent based models, cellular automata, self thinning systems, adapted L-systems or via a computer generated distribution. The following paragraphs will discuss each model and also discuss how these models can be linked to the vegetation models.

3.1 Agent based modelling

Emergence is the process in which complex systems are created by simple interactions. Agent based modelling models these interactions between plants and through this modelling process a complex system such as a vegetation is modelled. The interactions of the agents are steered by simple rules and using these rules the agents interact with other agents and their environment. But also plants as complex system can be simulated with an agent based model using the individual cells as agents. It is therefore a bottom-up process by going from a lower level of life to a higher, complex level of life.

An Agent Based Model is self-organizing. The interactions of all agents determine the organisation of the whole system and for example the spread of all agents will be based upon their interactions.

The following algorithms have been formulated to create vegetation:

- *Plants reproduce in their assigned season.*
- *Seeds are dispersed in different directions and dispersal agents, such as animals, are simulated by dispersing the seeds much further away.*
- *Seeds have a period of dormancy before suitable environmental conditions cause them to germinate; seeds expire if they are not germinated within an assigned period of time.*
- *Plant tolerance or adaptation to ecosystem factors is based on an upper, ideal, and lower value. Different plants have different values.*
- *Plants compete for availability of sunlight, space, and nutrients based on environmental conditions and the sizes and shapes of competing plants (Ch'ng, 2009).*

The agents have rules which define how they will act in the algorithm. Therefore knowledge of the agents is necessary to define the rules. This is different for each plant. The model will have to be calibrated and validated to test whether the model reflects reality. The calibration will require running the model over and over again and the total computation time might therefore be long (Longley P.A., 1999 p376).

The agent based model can be linked to a vegetation model and resulting map. However, it would require an agent based model for each vegetation type to be created, calibrated and validated and it is therefore very time consuming to link it to a vegetation map. This is necessary because the distribution should adhere to the descriptions of the vegetation types which result from the mapping process. It is also possible to generate the plant distribution with only input maps containing a digital elevation model, nutrients information etc. This would reduce the amount of models to one, but the link with the vegetation model will be lost. The agent based model is capable of modelling the vegetation itself and this partly overlaps with the vegetation mapping models.

A link between SMART2/SUMO and MOVE and an agent based distribution model is possible, because the results from MOVE describe which plants have to be modelled as agents and the model can be run for each $250m^2$ cell. It is however unclear how the layer information about biomass should be transferred through the Agent Based model to the 3D models which have to visualise this biomass and layers.

3.2 Cellular automata

Cellular automata are discrete models. Each cell in the model can have a state and this state can change in a time step. The state changes for each time step are guided by transition rules and neighbouring cells can influence the state of the cell (Balzter, Braun, & Köhler, 1998). A well known example of cellular automata is The Game Of Life developed by John Conway. This has three rules to define whether cells are alive or not (Longley P.A., 1999, p374).

The cellular looks very similar to agent based modelling, but a cell can be an aggregation of multiple agents. Therefore, no interaction within a cell can be modelled with cellular automata. It depends however on the process to be modelled whether a cell can be an agent or not. Nevertheless, the algorithms used in agent based modelling can also be used to define the transition rules in a cellular automata. Which algorithms can be used depends on the choices made for the duration of a time step, scale and possible states of a cell.

To model individual plants, the cell size needs to be very small and this will increase the amount of cells dramatically. This may cause long computation times. The choice on cell size is also very difficult, because too large cells can result in a very low amount of plants per square metre, which is not in line with reality. Too small cells can result in problems modelling plants which need more space than a cell can provide, which can result in large plants growing very close together, which isn’t the case in reality.

Cellular automata also require calibration and validation of the model. This requires a test dataset for comparison and the vast number of times to model has to be run will require long computation time (Longley P.A., 1999, p376).

The cellular automata will have to be created as many times as there are vegetation types to make a distribution for vegetation maps. It is in fact the same problem as with agent based modelling, because the same algorithms are used as with agent based modelling. The outcomes of the vegetation modelling however require that for each vegetation type a distribution has to be made based on the description of this vegetation type and this requires a separate model for each type to come to results that match the vegetation description.

The link between SMART2/SUMO and MOVE and cellular automata is possible in the same way as with agent based modelling. It is also unclear how the information about the biomass of all layers should be transferred via the cellular automata to the 3D plant models.

3.3 Self thinning distributions

Another approach to get a reality based distribution is to make a self thinning distribution. This method has been developed to model plant distributions in monocultures. The procedure for such a distribution is as follows: A large number of small plants are distributed over an area. These plants are grown and they will interfere with neighbouring plants because space is scarce. A plant dies when it has reached its maximum size. Plants die prematurely when it does not get the necessary resources or space (Firbank & Watkinson, 1985). This model does not incorporate as much variables and algorithms as the agent based model and the cellular automata do and is therefore easier to create. It might not be suitable to model a vegetation distribution, because it has been developed to model monocultures.

3.4 L-systems distributions

Lindenmayer (L-) systems have been developed by Aristid Lindenmayer to describe the topology of a plant initially. This has been extended later on with procedures for 3D drawing using turtle technology. This has given the possibility to create and visualise plants (Hanan, 1997).

The L-systems are a class of rewriting systems. A rewriting system consists of an alphabet, which is a set of symbols that can be present in the system, an axiom, which is the initial state and some productions, which describe the development. A very simple example of such a rewriting system is as follows: a string can contain the letters *a* and *b*. Two rules are present *a* -> *ab* and *b* -> *a*. The process starts with the predefined string which is the axiom. If the axiom is *b* and the production rules are applied each step, the result will be this: *b* -> *a* -> *ab* -> *aba* -> *abaab* -> *abaababa* -> *etc* (Prusinkiewicz & Lindenmayer, 1991, p3-4). Simulation of plant growth is where the L-systems originally have been developed for. These L-systems will be used to model 3D plant growth in this research. This however is extended with multisets to simulate vegetations as well. This multiset represents many plants and by adding or removing a string from this multiset, plants can be added or removed. The multiset is operated by a set of productions guiding the development of all plants.

The competition of plants is simulated by introducing the self thinning system into the L-system. The smaller plants which are dominated are removed from the system just like in the self thinning distribution (Lane, 2002).

3.5 Computer generated distributions

A computer generated distribution has a very low amount of input parameters and algorithms based on natural processes. The only necessary input data to create the vegetation is the type, frequency, placement and cover of plants. The use of Multi-fractal noise (Hammes, 2001) or the Hopkins index can simulate the clustering which plants tend to do (Lane, 2002).

The major advantage of computer generated distributions is that the distribution can be computed on the fly and that all the locations of the plants do not have to be stored. The camera position and the distance to the camera determine whether an area will get a distribution and will be rendered or not. Whether this on the fly distribution can be used depends on the used software (Hammes, 2001).

3.6 Conclusions on distribution modelling

Several modelling techniques exist to generate a plant distribution for vegetation areas. The simplest method is to let the computer generate the distribution of the plants with some input parameters on the type of plants and their abundance. A more advanced method is to use an L-systems distribution with multisets and production rules on this multiset. Another model called self thinning distributions, which could also be used without the L-systems model, is used to simulate the competition between plants. The most advanced models are Cellular Automata and Agent Based Modelling. They give the possibility to model all the interactions found in nature and can give, via the process of calibrating and validating, a distribution which is very similar to what is found in reality. These results cannot be achieved with simple techniques like computer generated distributions or self thinning distributions. These more advanced models however do require a lot of time and expert knowledge about the interactions between plants and between plants and abiotic circumstances. It is therefore not feasible to use these models and the simple and quick method of computer generated distributions will be used in this research.

4 3D growth models and 3D plant models

The growth of plants can be modelled with the L-systems model or with the AMAP model. These are complex 3D based on the growth processes which can be seen in reality (Muhar, 2001). It is also possible to create complex 3D plant models which are not based on reality. This can be done using general 3D drawing software or using plant design software such as Xfrog (Pradal et al., 2009). As already was described in the introduction, other methods of 3D visualisation of plants are available, but these methods, such as spheres or photographs placed on 'billboards' are insufficient for modelling small shrubs and herbs (Muhar, 2001). Therefore these simple methods will not be explained in detail any further and the focus will be on most promising techniques which are capable of modelling growth: L-systems and AMAP and on the complex 3D plant model technique of Xfrog.

4.1 L-Systems

Lindenmayer (L-) systems have been developed by Aristid Lindenmayer to describe the topology of a plant initially. This has been extended later on with procedures for 3D drawing using turtle technology. This has given the possibility to create and visualise plants (Hanan, 1997). The L-systems are a class of rewriting systems. A very simple example of such a rewriting system is as follows: a string can contain the letter *a* and *b*. Two rules are present *a -> ab* and *b -> a*. The process starts with a predefined string called the axiom. If the axiom is *b* and the rules are applied each step, the result will be this: *b -> a -> ab -> aba -> abaab -> abaababa -> etc.* (Prusinkiewicz & Lindenmayer, 1991, p3-4).

The turtle drawing technique is very simple. There are four commands: two for moving the turtle, one while drawing a line and one moving only and two for turning the turtle left or right by a given angle. This is for 2 dimensions. This has been extended to use in 3D by adding an indicator for the upwards direction and by adding controls for pitch and roll (Prusinkiewicz & Lindenmayer, 1991, p6-7). These two techniques have been converted to several languages such as cpfg or L+C, which can be used in software packages developed together with these languages to model plants (Pradal et al., 2009).

Figure 9 shows how this rewriting works on a leaf. The leaf is constructed of terminal branch segments called apices and of internodes. The first rule here states that an apex will branch into two new apices and that it will add two internodes and an apex on the main axis. This is clearly visible in the second structure from the left. The second rule states that the internodes will double in length. Each time step, more apices are added resulting in more branching and the internodes are added and they also grow which avoids overlap between all the branching apices. The leaf has self-similarity, because the different branches and the whole leaf are comparable to each other and shows in this way that L-systems are capable of modelling the fractal structures which can often be found in plants.

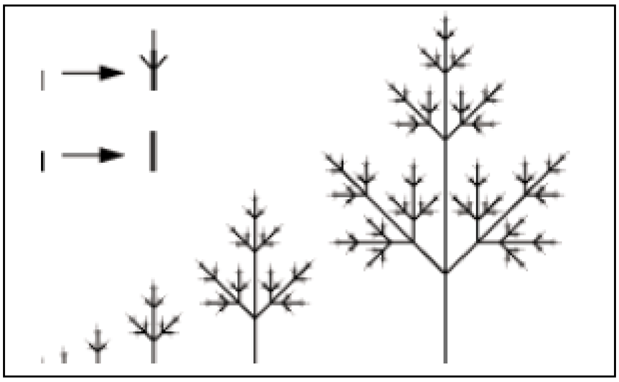


Figure 9: Simple L-system development (Prusinkiewicz, 2000).

A simple 3D plant has been described in the Algorithmic Beauty of Plants (Prusinkiewicz & Lindenmayer, 1991, p26).

The original L-system code in this book is as follows:

```
N=7, d=22.5

W = A
P1 = A -> [&FL!A]/////’[&FL!A]///////’[&FL!A]
P2 = F -> S/////F
P3 = S -> F L
P4 = L -> [’’’^^{-f+f+f-|-f+f+f}]
```

The axiom here is A and p1 creates three new branches from the apex of an old branch, p2 and p3 take care of the internode growth and p4 specifies the leaf. The number of times the systems is repeated is 7 and the angle for roll is 22.5 degrees. A list of all turtle operations can be found in Appendix A. This code results in the plant in Figure 10.

The L-system code which was used in PlantGL is as follows:

```
a = 22.5
Axiom: _(0.2)A
production:
A --> [&(a)FL!(0.1)A]/(a*7)[&(a)FL!(0.1)A]/(a*5)[&(a)FL!(0.1)A]
F --> S/(a*5)F
S --> FL
L --> [,(2)^(a*2){-(a)f+(a)f+(a)f-(a)|-(a)f+(a)f+(a)f}]
```

Figure 10: Povray render of the l-system code

As it is noticeable, the number of times the system is repeated is stated elsewhere and the angle is placed in the system itself via variable *a*. Furthermore, the roll command is no longer given five times in a row, but the angle for the roll is multiplied by five to get the same result. The plant in figure 10 has been exported from PlantGL to Povray and has been rendered with Povray.

This shows that the overall idea and commands to control the turtle moves and the set up of the system has remained more or less the same from the Algoritmic Beauty of Plants which was published in 1991 and the use in the PlantGL and OpenAlea software which was released in 2009. And this long period of use and development proves that it is a good technique for modelling the growth of plants in 3D.

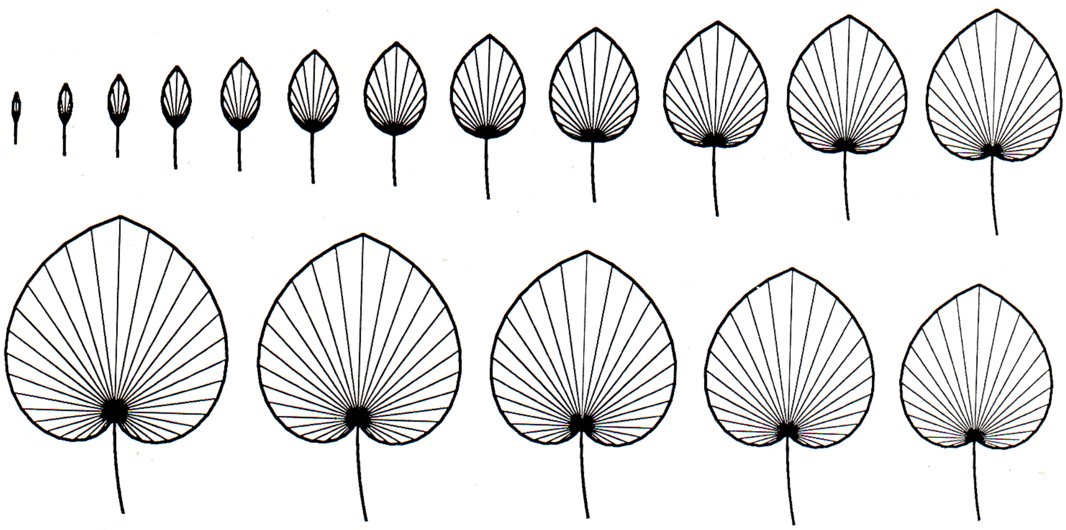


Figure 11: Leaf growth simulation with an l-system (Prusinkiewicz & Lindenmayer, 1991, p123)

The L-system can make 3D models of plants in all growth stages. Each time step or repetition of the L-system is a growth stage. This growth is realised by extending the internodes and by adding new branches at the apex. Or, to simulate leaf growth, by adding and extending the axes of a leaf as shown in Figure 11 (Prusinkiewicz & Lindenmayer, 1991, p123).

In order to model 3D plants and their growth accurate, it is necessary to study the growth and shape of each plant which is to be modelled (Mathieu et al., 2009). This is a time consuming process. The modelling is not easy as well, because the global structure of a plant is composed of the interaction of several rules. A change in one rule to change one aspect of the plant can therefore result in changes in other aspects as well. It is however also possible to use L-systems as a sketch tool. But when it is used as a sketch tool, the accuracy of the plant modelling gets lost and it will not longer be possible to generate 3D plant models for each growth stage which represent the shape of the real plant in each growth stage. Only one growth stage can me modelled sketch based (Anastacio, Prusinkiewicz, & Sousa, 2009).

4.2 AMAP

The AMAP system has been developed about twenty years ago to model trees in detail. The model techniques at that time, including the L-systems model, were not advanced enough to include the necessary mathematical algorithms to do detailed tree modelling.

The AMAP model is based upon a classification of tree types. The classification has been made on the axes combination of a tree. The combination of axes in a tree is based upon how a tree branches. The tree trunk is a first order axe and a branch from this trunk is a second order axe. If this branch branches again, it will be a third order axe. These second and third order are duplications of the first order architecture and the growth therefore reiterates with each new order. Using Monte Carlo simulation together with stochastic laws for mortality and branching, the growth of a tree is simulated.

To simulate a tree, field observations of this tree have to be taken and converted to be the input information for the growth simulation (Jaeger & De Reffye, 1992). The AMAP modelling method might very well link with the SMART2/SUMO model to model the biomass in 3D as it was modelled in SMART2/SUMO. This is achieved by including source-sink relationships in the tree and between the tree and the environment. The source sink relationships in the tree itself determine the biomass production and allocation. Figure 12 shows how this results in a different biomass distribution. The tree in the middle shows the growth under good environmental conditions. The tree on the right shows the growth under bad conditions. The leaves are concentrated near the top of the tree and it has less biomass. The tree on the left shows what growth under bad conditions should not look like: the tree is a small size copy of the tree in the middle and shows no effect of bad environmental conditions. These environmental conditions could include competition, the amount of light, etc. (Mathieu et al., 2009). The inclusion of these source sink relationships would require a lot of time to model for all plant species and has only been applied to trees, which makes hard to apply on shrubs and other vegetation.

Figure 12: Biomass modelling with AMAP: the middle tree shows the growth under good environmental conditions, the tree on the right growth under bad conditions and the tree on the left how a tree should not look like under bad conditions (Mathieu et al., 2009).

The AMAP model has been developed to model trees and whether it will be possible to apply a model which has been developed to model trees and used to model landscape development is suitable to model small shrubs and herbs is unclear.

Software exists which already has taken care of most of the modelling process. It simplifies the use of AMAP by offering hard-coded models. These models have parameters and by altering the parameters, the plants are built. The software has a library of 3D symbols for flowers, leaves and fruits to add to the plants (Pradal et al., 2009).

4.3 Sketch based plant models

The sketch based plant models can be created with general 3D software or with sketch based plant design software. The general 3D software is used for many purposes, such as creating games or for building 3D objects. Plants are of course objects too and the procedure to create the 3D plant is therefore very simple. The volumes and textures on these volumes will have to be defined according to how the plant looks like and when the 3D plant looks more or less the same as the real plant, the 3D plant is ready.

The sketch based plant design software already has a library for the basic plant organs like leaves, flowers or branches. By modelling these basic organs in a graph with multiplication operations, the plant is created. The major advantages of using this software are that the user does not need much biological knowledge to model a plant and that the basic shapes are already present in the software. Figure 13 shows how a simple plant is created with basic plant organs (Greenworks, 2009).

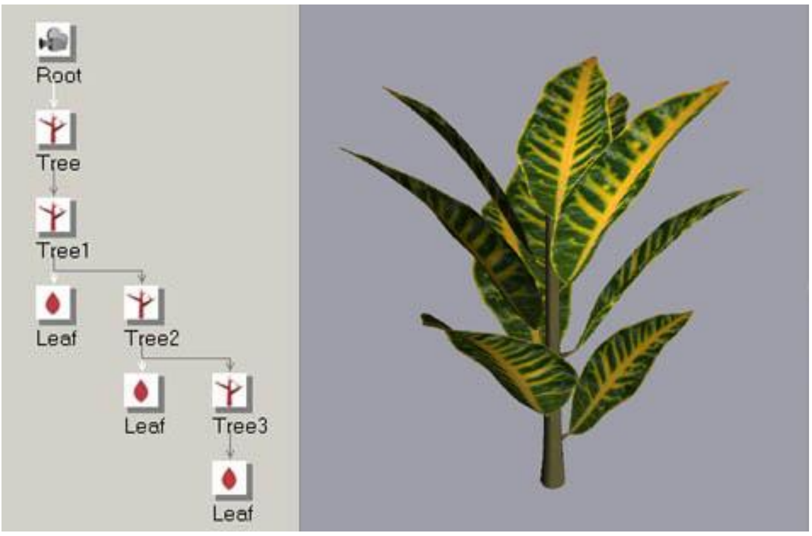


Figure 13: Modelling plants with Xfrog (Greenworks, 2009)

4.4 Conclusions on 3D plant models

There are two main methods to model a plant in 3D: growth modelling based on reality and sketch based modelling. Growth based modelling can be done with L-systems or with AMAP. The advantage of these models is the different growth stages and 3D models of it of a plant can be created with one model. Furthermore, it is possible to model the biomass with AMAP and the effect of the environmental conditions on the growth and shape of the tree. This would be very useful when it would be used for 3D visualisation of vegetation succession models. The advantage of sketch based modelling using Xfrog is that it is possible to create a 3D plant model in very short time and without much biological knowledge.

The L-systems rewriting technique and the Xfrog software will be used to create a number of 3D plants for the case study. Software to create L-systems is available as open source software and Xfrog is available with a 30 days evaluation period and they are therefore both easy to obtain.

5 Data quality of vegetation maps

Using maps for other goals then the goal which they are originally created for can cause a lot of problems. This chapter will briefly discuss the possible problems as they are described in An Introduction To Geographic Information Systems by Heywood et al (2006) and Principles of Information Systems by Burrough and McDonnell (1998). A vegetation map could have a very good quality in terms of thematic accuracy, positional accuracy and temporal accuracy (Burrough & McDonnell, 1998, p221) and still not be very suitable to use it for 3D visualisation of vegetation. Factors which might degrade the quality of the 3D visualisation are the generalisation used of the input vegetation map, the coverage, the error propagation of the vegetation map, insufficient modelling of fuzzy boundaries and the selection process for the area to be mapped.

5.1 Generalisation in the vegetation maps

A vegetation map is a heavily generalised model of the reality. The reality is an area with a mixture of plants, but this is in the map classified into vegetation types. This classification process is one of the types of generalisation and one in which human intervention, interpretation and choices influence the classification. Another reason for generalisation of the data can be that the data is required at a specific scale and details might get lost when for instance the features are simplified. The last reason for generalisation of the map is the technical limitations from the process which was used to create the map. This could be for instance the resolution of a remote sensing device (Heywood, 2006, p43), but it could also be in the geostatistical interpolation process. The vegetation mapping for Ameland had for instance five main vegetation types of which two were sub divided into sub-vegetation types. This vegetation map has been created using kriging, which requires enough sample points to calculate the variogram (Burrough & McDonnell, 1998 p137). It is therefore necessary to have enough sample sites per vegetation type. Because one vegetation type was only found at one sample site, it was left out of the dataset. The area to be interpolated remained the same however and the point which was left out has therefore got another vegetation type assigned in the final vegetation map. Furthermore, the sub-vegetation types have been aggregated to their main categories to increase the number of sample sites per vegetation type (Slim, 2005).

The implication of this generalisation process is that the details which get lost during this process cannot be 3D visualised and that the differences in vegetation composition between the two sub types will not be visible in the 3D visualisation. Another implication is that it might insert an error when a vegetation type is 3D visualised at a location which is in reality and in the original dataset another vegetation type.

5.2 Fuzzy boundaries

The changes between entities can be gradual. This can be found in nature in soil types, groundwater data and vegetation types. These boundaries are therefore indistinct, which makes them hard to represent on a chorochromatic map. In order to solve this problem, these features are made distinct by drawing a sharp boundary between the differing entities, which makes it looks like it has as well been defined as a cadastral unit (Burrough & McDonnell, 1998, p224-225; Heywood, 2006, p311).

This fuzziness is very much related to the definition process of an entity. It is for instance possible to have different definitions for what a mountain, such as the Mount Everest exactly is and therefore what is included in the entity Mount Everest and what not. The different aspects which make up the Mount Everest make discussion about these aspects and therefore the entity itself possible(Heywood, 2006, p306).

A vegetation type is also made up of different plant species which together form the characteristics of the vegetation. The classification of these vegetation types is done via plant species which give the vegetation its unique character. Each plant in turn responses differently to for instance the amount of available water and the height differences (Slim, 2005). These differences in response will therefore result in fuzzy boundaries between vegetation types due to differing distributions of the different species which make up the vegetation type. To illustrate this: A rising ground water level to the north could for instance stop plant species X after 50 meters to the north, whereas plant species Y will continue to grow with these high ground water levels up until 100 meters to the north. The north area can be classified as a wet vegetation type, whereas the south area is classified as a dry vegetation type. A sharp boundary might be drawn where plant species X stops to grow, but also where plant species Y stops to grow. But in reality, the vegetation changes gradually from dry to wet.

The effect of these sharp map boundaries will be clearly visible boundaries where all plants belonging to the one vegetation type will stop to grow and the all plants from the other vegetation type will stop to grow. In reality however, some plants of the first vegetation type will continue to grow for a limited distance in the other vegetation type.

By making the vegetation visualisation less abstract than a traditional chorochromatic map by using a 3D visualisation, it will be easier to compare the distribution of a specific plant species in reality with the distribution of this plant species in the 3D visualisation. It is therefore expected that these boundaries from the vegetation map will result in distribution errors for the individual species and will show boundaries that not exist in reality.

5.3 Completeness

The coverage of the vegetation map should be complete (Heywood, 2006, p304). A gap in the vegetation map will appear in the 3D visualisation as an area missing 3D plant models and unless the area has been mapped as an area with no vegetation, it is no good representation of reality. The gaps in the map will look exactly the same as an area without vegetation would do and the user of the 3D visualisation can therefore no longer spot these errors in the data. The user will interpret these gaps in the map as areas without any vegetation.

There might of course be good reasons for these holes in the vegetation maps. For instance a small area with water could well be completely within the vegetation map. These water areas which appear as gaps in the map can however visualised distinct from the areas without vegetation by covering all areas below sea level with a water texture in the 3D visualisation or by using a aerial photograph as a texture on top of the DEM which has a good representation for the water for the vegetation gaps.

But because gaps in the map do not make clear themselves why they are there, it is necessary to check for each gap in the vegetation map why it is there using other maps, a DEM or an aerial photograph of that area.

5.4 Error propagation

Vegetation maps are often created using other geographic data. When these other datasets contain errors, these errors can continue in the vegetation map and in the end in the 3D visualisation of this vegetation map. If there is lineage information available about the vegetation map, it should be possible to track these errors down to the input datasets. This information however is not always created along with the data processing (Heywood, 2006, p305-326).

Because the 3D visualisation differs from the traditional map visualisation, it is very well possible that errors in the dataset do not manifest themselves or that these errors will be clearly visible, more than they were in the original map. If the 3D visualisation does have strange results, such as for example 3D models of plants at impossible locations, it would be good to inspect the input datasets to check where this strange result is caused by.

5.5 Using raster vegetation maps

Raster maps containing vegetation can also be used as input for 3D vegetation visualisation. What makes raster maps special here is that the grid cell is less flexible compared to a vector feature. Grid cells can contain only one value and have a fixed size (Burrough & McDonnell, 1998, p231). If the size of the cell is large, it will result in a 3D vegetation visualisation which has still visible grid cells when there are large differences between the vegetation types of these grid cells. This assumption is based on the research of converting land use models to 3D visualisations by Borsboom-van Beursden et al (2006, p90-97) and Van Lammeren et al (2005, p138). Figure 14 shows how this raster map of the land use model is converted to a 3D visualisation of land use. The raster origin of the 3D visualisation is still clearly visible. Smaller grid cells can be capable of modelling this change more gradually.

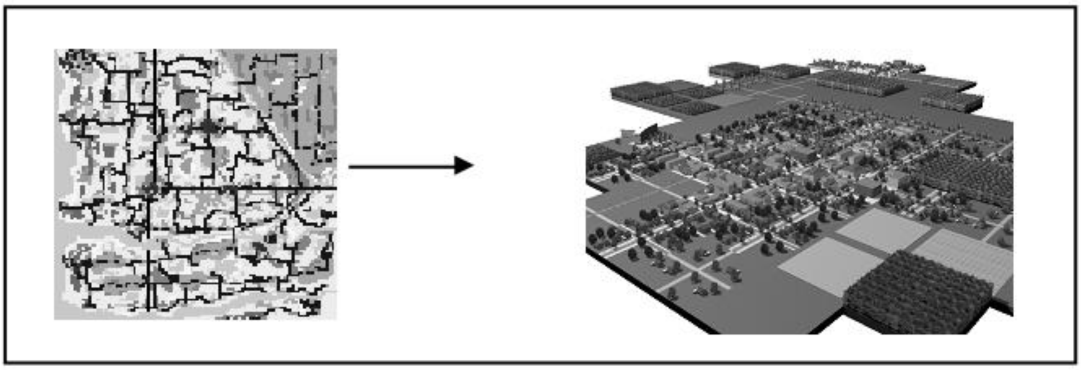


Figure 14: 3D visualisation of raster land use maps with a large raster cell size will result in a 3D visualisation with a raster pattern (Lammeren, 2005, p138)

Another problem which might occur when using raster data is the mixed cells problem. A grid cell can only contain only one value and it might therefore be possible that a large grid cell having a certain value should contain other things apart from the vegetation value (Burrough & McDonnell, 1998, p231). It is very likely that a grid cell of 250^{m2} containing heath is overlapping a small fen which is situated in this heath. A vector map is capable of excluding this fen, but if a raster map is used, the distribution of plants will also be made within this fen.

On the other side, if this water area is large enough to cover one or more grid cells completely, it is very likely that these grid cells will be assigned no data. But when slightly more than half of this grid cell is part of this water area and the rest is part of the land and contains vegetation, the land area of this grid cell will be seen as water as well. The implication of this will be that there will be no plant distribution for this area, because the vegetation type is not known.

These problems can be solved by combining the raster data with vector data. When the raster map and a suitable vector map are overlaid, it is possible to remove the small areas which don’t need a vegetation distribution from the raster map. Furthermore, it is possible to check on areas which are likely to have vegetation, but which are assigned no data by the raster map. This technique is based on the overlay which is used in land use modelling by Borsboom-van Beursden et al. (2006, p96), which use this overlay technique to combine future land use as it was computed on a raster map with current infrastructure and water areas to keep these features in the future land use plan.

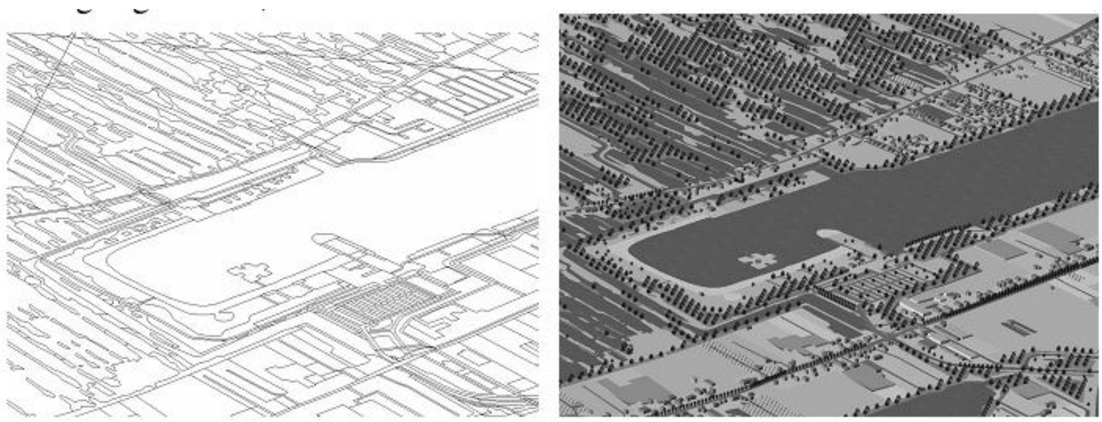


Figure 15: Combination (right) of a raster land use map and a vector topographic map (Borsboom-van Beurden, 2006, p96)

5.6 Conclusions on the data quality of input vegetation maps

There is one obligatory check before a vegetation map can be 3D visualised: checking on gaps in the input vegetation map. If there are gaps in the vegetation map, they will be 3D visualised as areas without any vegetation, which is not indicated by the map. If there are gaps, it should be checked whether the DEM and aerial photograph can offer an understandable and reality based visualisation for such a gap.

Other errors from the input data might be exaggerated by the 3D visualisation and become very clearly visible in the 3D visualisation. It is therefore also necessary to check the 3D visualisation for errors and to search for the cause of an error. If possible, this error should be corrected in the input data so that it does not shows up in the 3D visualisation.

Other problems which can be encountered when creating a 3D visualisation could be a high level of generalisation and non-reality based sharp boundaries between vegetation types. These will lead to 3D visualisations which might deviate from reality and thereby give the user of the 3D visualisation a wrong idea of the real or future situation of an area. These problems however originate from the choices which are made with the traditional vegetation map in mind and these choices therefore limit the use of the vegetation map for 3D visualisation. An input vegetation map which is created solely as an input map for 3D vegetation visualisation will therefore be only generalised where necessary for the data collecting process. It should still contain sharp boundaries, because it is not known how the distributing process should cope with fuzzy boundary vegetation maps.

When raster maps are used as input data, it will need some pre-processing with vector data to check on small features which should be excluded from the vegetation and to check whether all vegetation areas are included in the raster map. Raster maps with a large cell size are also likely to make the 3D visualisation look like a raster viewed from a distance.

The results of this chapter will be used later in this thesis to discuss the achieved results in the case study.

6 The Ameland case study

Figure 16 shows the 3D vegetation visualisation process again. This 3D visualisation process will be used in a case study situated at the island Ameland. The corresponding paragraphs are displayed in bold. First, the vegetation maps and necessary data which will be the input to the plant distribution tool will be discussed in 6.1. Then, the 3D plant modelling process will be discussed in 6.2. The software used to create the plant distribution and to 3D visualise it will be introduced in 6.3.1.

The figure has been extended with an extra line from the geographic input data to the 3D vegetation visualisation compared the original figure in the introduction. This has been done, because some of these datasets which have been used before to create the vegetation maps can also be useful to improve the realism of the 3D visualisation. Another dataset has been added to model the vegetation descriptions. These descriptions describe the composition of the vegetation types and are necessary to create a plant distribution for a vegetation type. For this research, the compositions of the vegetation types have been derived from a dataset containing all the plant recordings in the research area. The dashed line represents the information which is needed to select the plants which have to be modelled. This selection process has not taken place in this research and the line is therefore dashed, but it should have been done, more information on this can be found in the discussion.

A digital elevation model will simulate the height in the 3D visualisation and an aerial photograph will provide the texture which can be placed upon this digital elevation model to give the dunes, beach etc a realistic colour. The digital elevation model will be discussed in 6.3.2 and the aerial photograph will be discussed in 6.3.3. The computer generated distribution will be discussed in 6.4.3. The results from the 3D visualisation process will be shown in paragraph 6.4 and 6.5 will be the conclusions on the suitability of the used software. Paragraph 6.6 will contain a conclusion on the case study.

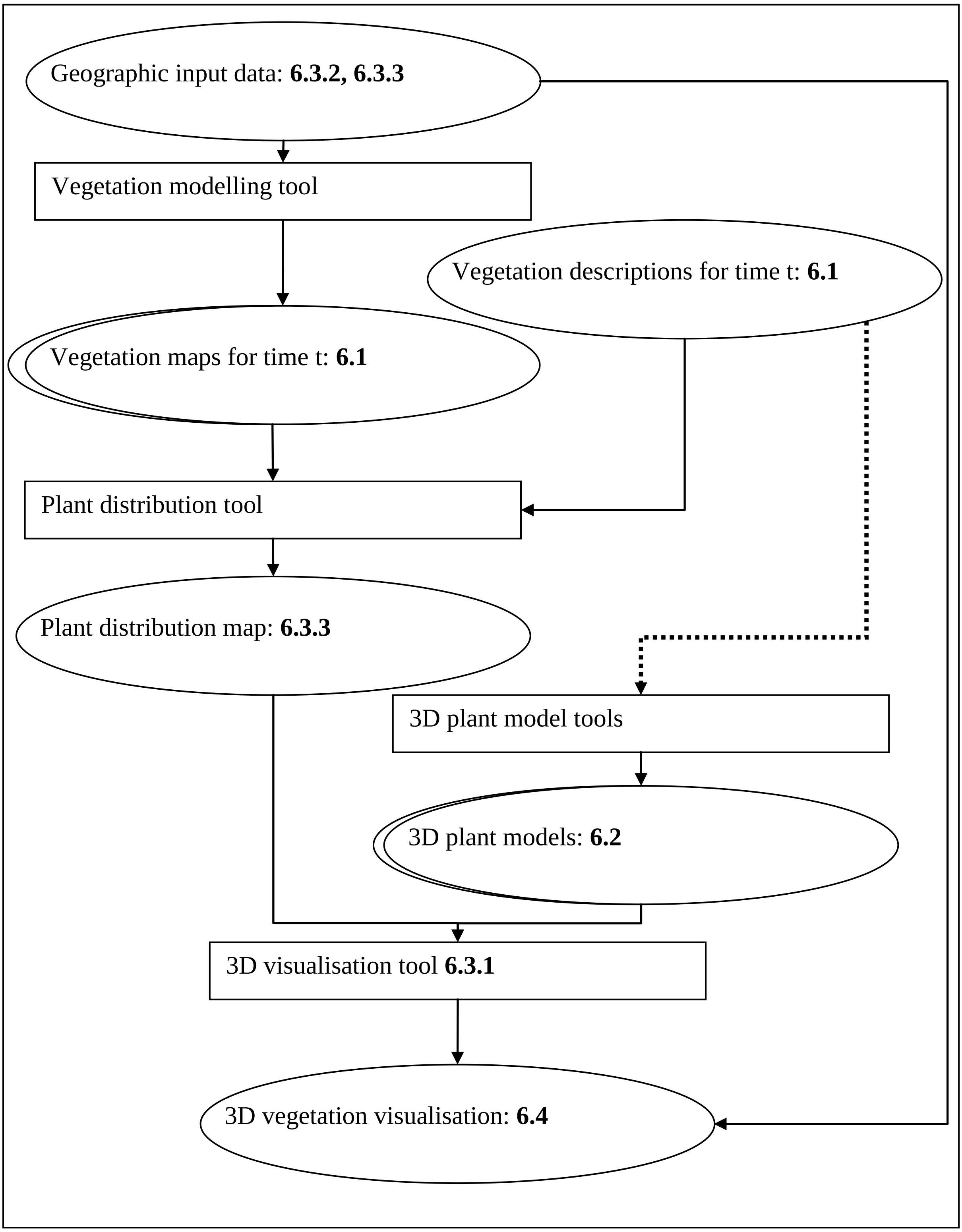


Figure 16: Modified schematic overview of the 3D vegetation visualisation process

6.1 The input vegetation data

The input data for the 3D vegetation visualisation are the vegetation maps of 2001, 2004, 2006 and 2008 and the points at which the vegetation was recorded. This map does not contain any gaps and is therefore suitable for vegetation visualisation. It is assumed that this map is correct and that all the vegetation types as shown on the map are also present in reality. There is also a database available with all the plant recordings including the location which can be joined to this point map. Figure 18 shows the vegetation maps for 2001, 2004, 2006 and 2008. Note that the map of 2001 differs from the map presented in the introduction. The reason is unknown and the input data for these maps comes from the dataset as it was delivered by the university. The areas with the different vegetation types don't show many differences between all the years. Zooming in to a very detailed level will reveal some minor differences. The distribution of the plants however does differ through the years. As an example, the vegetation recording points where the Potentilla anserina was found are shown in the maps. The year 2001 has fewer points in total and therefore a comparison between the absolute number of points is impossible over all the four years. It is however possible to see an increase of points between 2004 and 2006 on the one hand and 2008 on the other hand. But over the four years it is visible that this plant has started to grow in other vegetation types than B where it only grows in 2001. This resulted in differing vegetation compositions over the years and in order to make a good distribution of the plants the different compositions will have to be calculated. To do so, it is assumed that the vegetation composition is homogeneous over the whole area of one vegetation type. This assumption makes it possible to calculate a mean cover percentage of a plant species for a vegetation type for a year. Furthermore it was assumed that the mean cover percentage of the recording locations would be the same as the mean cover percentage of the whole area of one vegetation type. On this basis, the vegetation compositions were calculated.

A number of steps had to be taken to create the vegetation compositions. Figure 17 contains the model showing the first steps for the Potentilla Anserina for the year 2001. First, all the points containing one of the 3D visualised plants were extracted from the database containing all the names and plant recordings. This resulted in five database files containing the point where the vegetation was measured, the species database number and the cover code (Figure 17: Potenans Table). Another database file was extracted from the large database containing all the cover codes and the cover percentages (Figure 17: COVERTABLE). Then an extra field was added to store the cover percentage (Vegpoints2001_COVER) into and for each plant and for each year a copy (Figure 17: Vegpoints2001_pontenans_COVER) of the shape file containing all the recording locations (Figure 17: Vegpoints2001) was made. The database file containing all the recordings of one plant type was then joined in ArcMap to its corresponding copy of the point shape file (Figure 17: potenans2001). The database file containing the cover percentages was then also joined to all these files (Figure 17: potenansCoverperc). Figure 19 shows a part of the attribute table of one of these shape files. This results for each plant and for each year in a shape file containing all the recording locations and on the locations where this plant type is found information about the cover code and the cover percentage. If that plant species has not been recorded at a location all the fields belonging to the plant database file or the cover percentages table contain <Null>. The next step would then be to calculate the mean cover percentage for all locations, including the locations where the plant doesn't occur. This can however not be done on the right column "BEDEKKING2", because the <null> values will not be evaluated by the statistics tool of ArcMap. Therefore all the cover percentages were copied to the COVER column on the left and all the places where the plant didn't occur were given a zero. This COVER column was now ready for statistics calculation. However as is clearly visible in the most left column, all the vegetation types are present in this table. Therefore, for each vegetation type the points being in this vegetation type were selected. With this selection the mean cover of this plant in the selected vegetation was calculated. The results from this process can are in table X. The complete table with the mean, standard deviation and number of records can be found in appendix B.

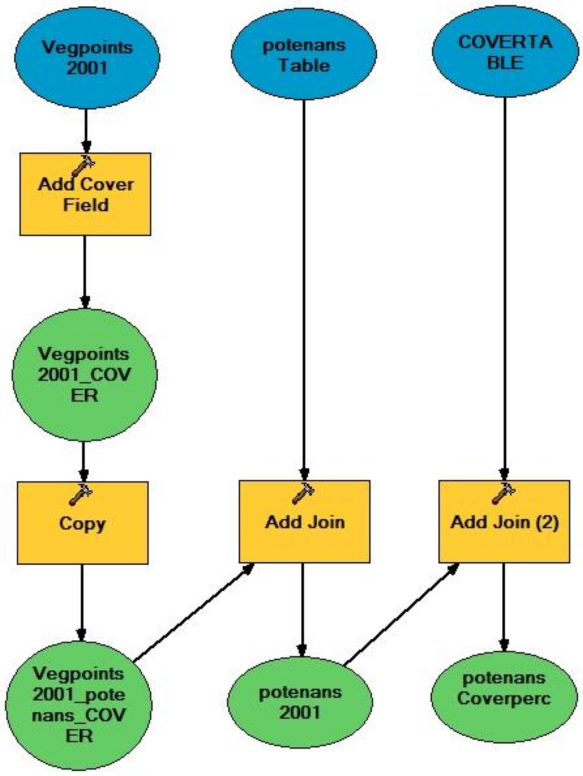


Figure 17: Joining the cover percentage to the plant recording points

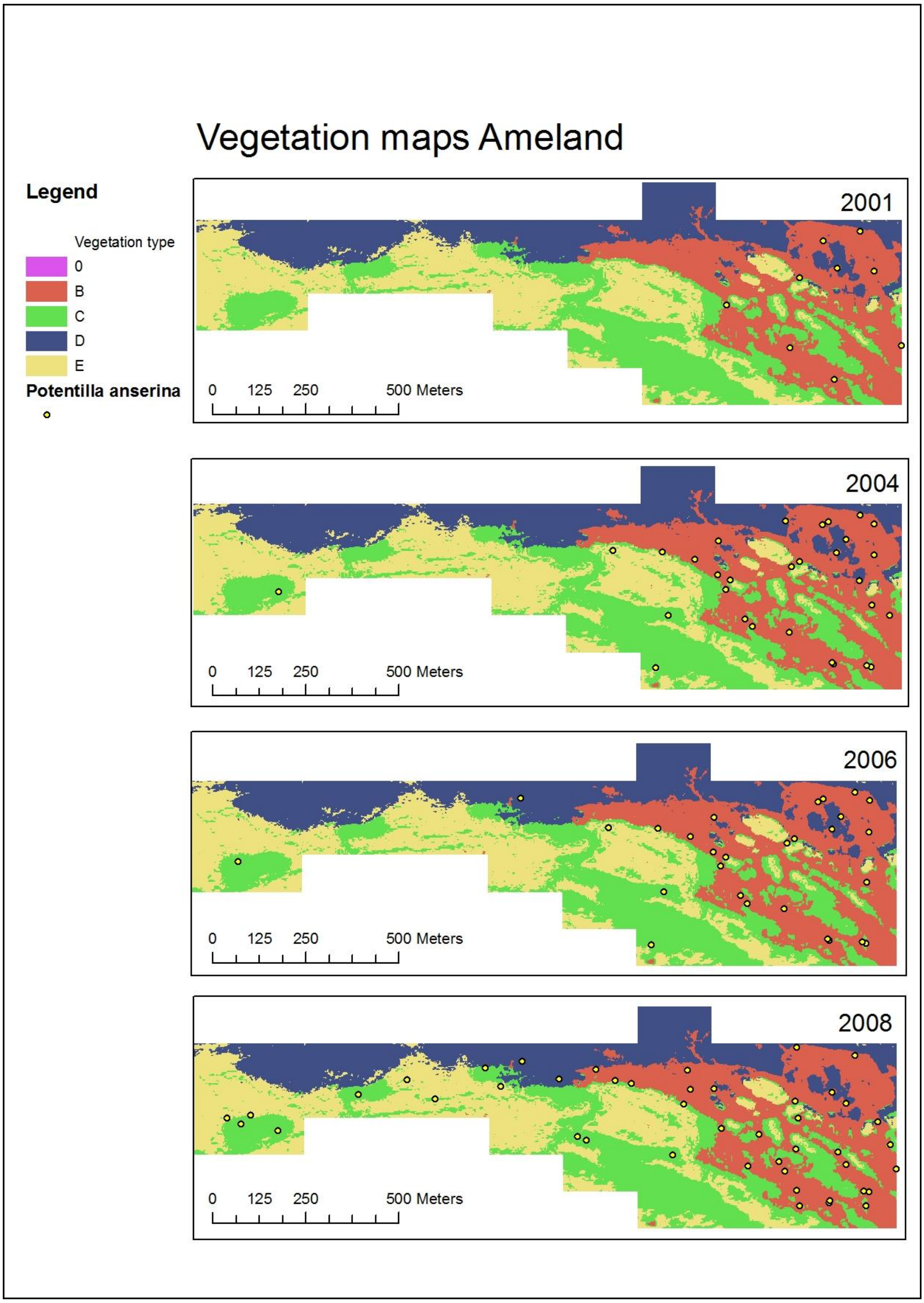
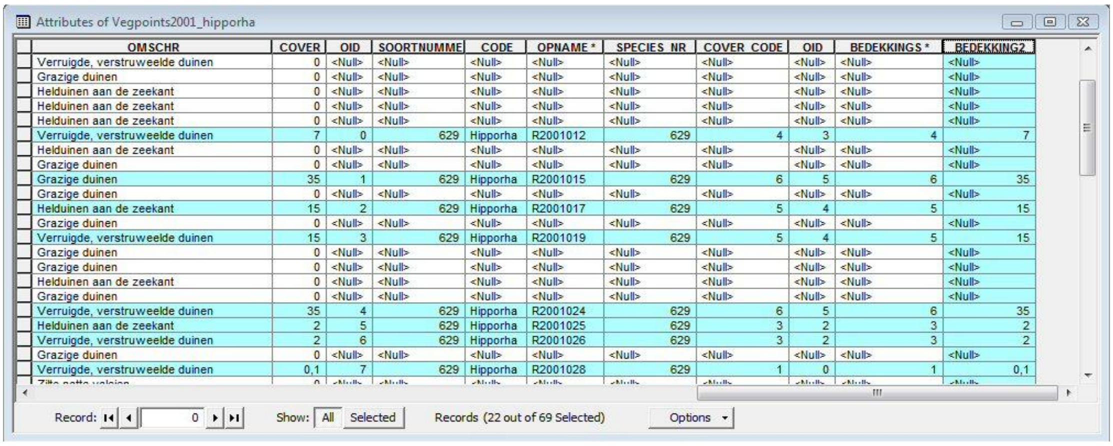


Figure 18: Vegetation maps of 2001, 2004, 2006 and 2008 with the dispersion op Potentilla anserina



Attributes of Vegpoints2001_hipporha

OMSCHR	COVER	OID	SOORTNUMME	CODE	OPNAME *	SPECIES NR	COVER CODE	OID	BEDEKKINGS *	BEDEKKING2
Verruigde, verstruweelde duinen	0	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Grazige duinen	0	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Helduinen aan de zeekant	0	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Helduinen aan de zeekant	0	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Helduinen aan de zeekant	0	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Verruigde, verstruweelde duinen	7	0	629	Hipporha	R2001012	629	4	3	4	7
Helduinen aan de zeekant	0	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Grazige duinen	0	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Grazige duinen	35	1	629	Hipporha	R2001015	629	6	5	6	35
Grazige duinen	0	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Helduinen aan de zeekant	15	2	629	Hipporha	R2001017	629	5	4	5	15
Grazige duinen	0	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Verruigde, verstruweelde duinen	15	3	629	Hipporha	R2001019	629	5	4	5	15
Grazige duinen	0	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Grazige duinen	0	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Helduinen aan de zeekant	0	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Grazige duinen	0	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Verruigde, verstruweelde duinen	35	4	629	Hipporha	R2001024	629	6	5	6	35
Helduinen aan de zeekant	2	5	629	Hipporha	R2001025	629	3	2	3	2
Verruigde, verstruweelde duinen	2	6	629	Hipporha	R2001026	629	3	2	3	2
Grazige duinen	0	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
Verruigde, verstruweelde duinen	0,1	7	629	Hipporha	R2001028	629	1	0	1	0,1

Record: 0 Show: All Selected Records (22 out of 69 Selected) Options

Figure 19: Attribute table showing the joined tables and the cover percentages (BEDEKKING2) which are copied to the new cover field (COVER).

	2001 mean	2004 mean	2006 mean	2008 mean
Vegetation type 0				
No plants	**0,000**	**0,000**	**0,000**	**0,000**
Vegetation type B				
Potentilla Anserina	**19,793**	**18,586**	**9,414**	**16,031**
Juncus maritimus	**0,000**	**1,207**	**1,207**	**0,060**
Hippophae rhamonides	**6,786**	**6,817**	**4,572**	**2,274**
Scirpus Maximus	**0,164**	**2,048**	**0,638**	**1,154**
Triglochin maritima	**0,000**	**0,003**	**0,000**	**0,000**
Vegetation type C				
Potentilla Anserina	**0,000**	**1,435**	**0,724**	**4,919**
Juncus maritimus	**0,000**	**0,000**	**0,000**	**0,000**
Hippophae rhamonides	**5,575**	**13,276**	**11,500**	**6,856**
Scirpus Maximus	**0,000**	**1,135**	**1,351**	**0,472**
Triglochin maritima	**0,000**		**0,000**	**0,000**
Vegetation type D				
Potentilla Anserina	**0,000**	**0,003**	**0,003**	**0,774**
Juncus maritimus	**0,000**	**0,000**	**0,000**	**0,000**
Hippophae rhamonides	**3,513**	**5,861**	**6,665**	**10,794**
Scirpus Maximus	**0,000**	**0,000**	**0,000**	**0,000**
Triglochin maritima	**0,000**	**0,000**	**0,000**	**0,000**
Vegetation type E				
Potentilla Anserina	**0,000**	**0,000**	**0,000**	**0,063**
Juncus maritimus	**0,000**	**0,000**	**0,000**	**0,007**
Hippophae rhamonides	**4,883**	**6,453**	**6,067**	**6,546**
Scirpus Maximus	**0,000**	**0,000**	**0,000**	**0,002**
Triglochin maritima	**0,000**	**0,000**	**0,000**	**0,000**

Table 1: Cover percentages of the plant species for each vegetation and each year

6.2 The 3D plant models

The 3D plant models have been created with Visualea/PlantGL and Xfrog. The choice of the plants has been made arbitrarily, because the datasets with the information on cover percentages and specie abundance was not available at that time. Furthermore there were only photographs available of eleven different plant species, which also limited the choice for the plants to be 3D modelled. In the end, the plants which seemed most feasible to be 3D modelled were chosen.

Initially, the number of plants to be modelled were evenly distributed over the two software packages, but because Xfrog was very easy to use, which resulted in less time spend per specie, it was decided to model two plants in PlantGL and the others plants in Xfrog. The 3D modelling process of the two plant species in Visualea/PlantGL will be discussed and then the 3D modelling process of the other four plant species in Xfrog will be discussed.

6.2.1 VisuAlea/PlantGL 3D plants written in L-systems

The first plant which is modelled with Visualea and PlantGL using L-systems is Scirpus Maximus. Figure 21 shows this plant growing in the research area.

This plant grows on the borders of salt and fresh water. Figure 20 shows a Povray render from the modelling in PlantGL and VisuAlea. The code which was used to come to this result is shown in Table 2. The L-systems code is more extended compared to the example in 4.1. The L-systems code now includes a homomorphism. This section is used to replace specific characters in the L-Systems string with other characters, but this replacement is only used for the turtle interpretation and it is not added to the new string for the next time step. The B stands for the brown flower at the top of the stem and in the homomorphism, the turtle commands are given to create this brown flower. Because this plant grows by enlarging the internodes and by adding segments on top of the plant the flower would be duplicated each time a segment is added. The production rule for B avoids this by removing the B from the previous string. This L-system also lets the leaves grow by adding extra segments to the middle parts of the leaf. Another improvement to this L-system are the variables which are processed through the rewriting process. The production rules for the A segment make the diameter of the main stem smaller by reducing variable *b* by 30% and simulate by this the smaller diameter of the stem near the top of this plant. The *c* variable in turn increases the growth speed of the internodes by enlarging the internodes length each time step. Older internodes therefore grow relative more than new internodes.

The other plant modelled with L-systems is Potentilla anserine (Figure 22). The L-systems code of Scirpus Maximus has been adapted to get a 3D model for this plant. This is because the L-systems code is difficult and abstract. It was therefore easier to recycle the code and to adapt it than it was to create the code from zero. The L-systems code of this plant is shown in Table 3. The angle (a) has been set higher to get more compact leaves and two additional branches have been added to the axiom and a special branch for the flower has been added as well. This flower is again modelled with a homomorphism. This has resulted in the 3D model of this plant as shown in Figure 23.

Figure 20: PlantGL model of Scirpus Maximus

Figure 21: Scirpus Maximus (photograph: Van Dobben)

```
a = 7
ab = 21
b = 0.1
l = 0.2
c = 1
Axiom: _(b)A(b, c)
production:
A(b, c):
  b = b - b*0.3
  c = c + 0.5
  produce [,(2)!(b)&(a)F(c)A(b, c)LB]
F(c):
  produce /(a*5)F(c)
L:
  produce [^(a){-(a)f+(a)f(3)+(a)f-(a)|-(a)f+(a)f(3)+(a)f}]
f(3):
  produce f(3)f(3)
B:
  produce *
homomorphism:
B:
  produce,(1)[&(a*3)[^(a){-(ab)f(l)+(ab)f(l)+(ab)f(l)-(ab)|-(ab)f(l)+(ab)f(l)+(ab)f(l)}]/(72)[^(ab){-
(ab)f(l)+(ab)f(l)+(ab)f(l)-(ab)|-(ab)f(l)+(ab)f(l)+(ab)f(l)}]/(72)[^(ab){-(ab)f(l)+(ab)f(l)+(ab)f(l)-(ab)|-
(ab)f(l)+(ab)f(l)+(ab)f(l)}]/(72)[^(ab){-(ab)f(l)+(ab)f(l)+(ab)f(l)-(ab)|-(ab)f(l)+(ab)f(l)+(ab)f(l)}]/(72)[^(ab){-
(ab)f(l)+(ab)f(l)+(ab)f(l)-(ab)|-(ab)f(l)+(ab)f(l)+(ab)f(l)}]],(2)/(36)[^(a){-(a)f+(a)f(3)+(a)f-(a)|-
(a)f+(a)f(3)+(a)f}]
```

Table 2: L-systems code of the Scirpus Maximus 3D plant model

Figure 22: Potentilla Anserina (photograph: Van Dobben)

Figure 23: PlantGL model of Potentilla Anserina

```
a = 30
ab = 50
b = 0.1
l = 0.5
Axiom: _(b)&(a)A(b)/(a*5)&(a)A(b)/(a*3)&(a)A(b)/(a*5)&(a)Z(b)
production:
A(b):
  b = b - b*0.3
  produce [,(2)!(b)FA(b)/(90)L/(180)L]
Z(b):
  b = b - b*0.3
  produce [,(2)!(b)FZ(b)B]
F:
  produce &(a/10)F
L:
  produce [^(a)/(90)!(0.01)F(0.5){-(a)f+(a)f+(a)f-(a)|-(a)f+(a)f+(a)f}]
B:
  produce *
homomorphism:
B:
  produce,(4)^(a*2)[[^(a){-(ab)f(l)+(ab)f(l)+(ab)f(l)-(ab)|-(ab)f(l)+(ab)f(l)+(ab)f(l)}]/(72)[^(ab){-
(ab)f(l)+(ab)f(l)+(ab)f(l)-(ab)|-(ab)f(l)+(ab)f(l)+(ab)f(l)}]/(72)[^(ab){-(ab)f(l)+(ab)f(l)+(ab)f(l)-(ab)|-
(ab)f(l)+(ab)f(l)+(ab)f(l)}]/(72)[^(ab){-(ab)f(l)+(ab)f(l)+(ab)f(l)-(ab)|-(ab)f(l)+(ab)f(l)+(ab)f(l)}]/(72)[^(ab){-
(ab)f(l)+(ab)f(l)+(ab)f(l)-(ab)|-(ab)f(l)+(ab)f(l)+(ab)f(l)}]]
```

Table 3: L-systems code of the Potentilla Anserina 3D plant model

6.2.2 Xfrog 3D plants

Xfrog is very user friendly and intuitive when it comes to modelling plants. Therefore more plants where modelled with Xfrog than originally planned, because it costs relative very little time to achieve a result which is more or less the same as the photograph which serves as the example. The plants modelled in Xfrog are Juncus maritimus, Triglochin maritima, Armeria maritima and Hippophae rhamonides.

The first plant to be modelled is Juncus maritimus. Figure 24 shows a photograph of this plant which was used to model the plant in 3D on the left, the 3D model of this plant in the middle and the model which was used to create the 3D model on the right. At first glance the plant might have a different look, but for this model it was strived for to achieve the brownish color more or less and to model the plant tops with the branches and little spheres. To do so, the model starts with a phiball which gives 12 points of origins from which the stems, which are modelled by a horn originate. This first long stem has another phiball on top of it to make 3 branches of the stem which are modelled by another, shorther horn, this process is repeated another time to make 3 more branches on each branch and in the end, a phiball is added from which 3 simple spheres originate. These steps are copied four times with different stem lengths in the horns to take care of the different lenghts of the stems.

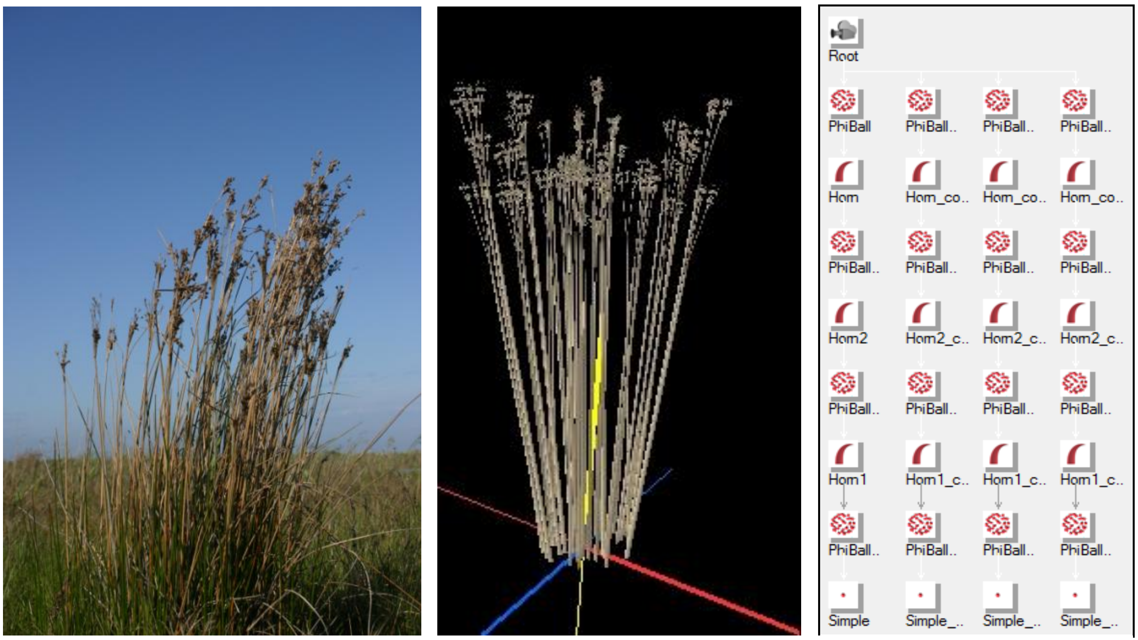


Figure 24: Juncus maritimus photograph (photograph: Van Dobben), 3D model and model tool

The second plant to be modelled in Xfrog is the Triglochin maritima. Figure 25 shows a photo of this plant which was used to model this plant on the left, the 3D model of the plant in the middle and the Xfrog model on the right. This model is a very simple one. It starts with a stem without flowers, which is followed by a stem with flowers. On each segment of this last stem an branch is attached, which is Horn1 in the model or the third element from top to bottom. Attached to this branch is a simple sphere and attached to this sphere a phiball creating five points of origin for the white petals of the flower. The distribution of all the flowers around the stem is done via a screw of the stem and the curvature is done via a spline.

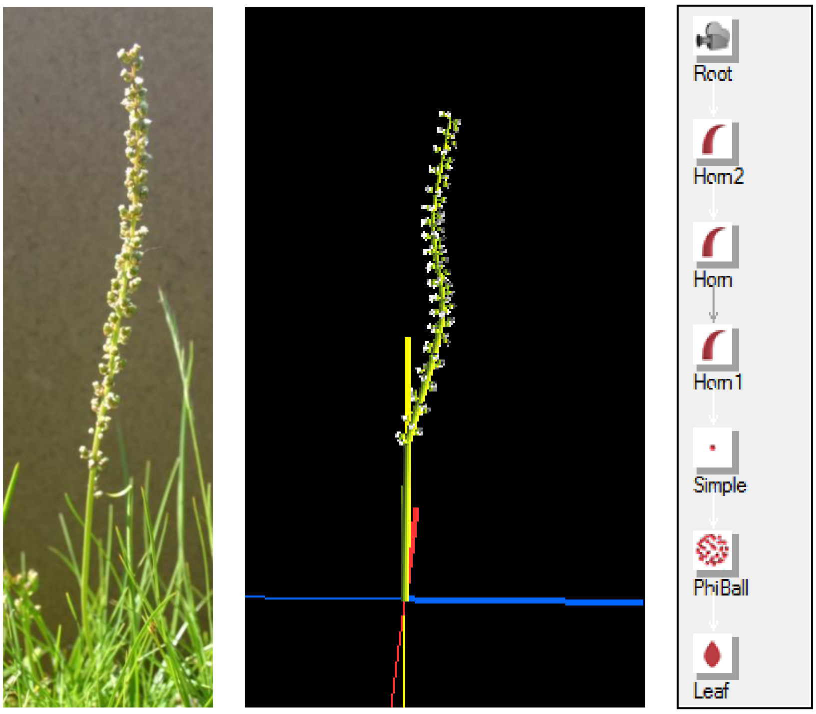


Figure 25: Triglochin maritima photograph (photograph: Van Dobben), 3D model and model tool

The third plant which was modelled in Xfrog is Armeria maritima. Figure 26 shows a photograph of this plant which was used to model this plant on the left, the 3D model of the plant in the middle and the Xfrog model on the right. This model is again very simple. It starts with a green stem with the first horn from the top of the model, which is continued in brown by the second horn. This is followed by two phiballs. The first one on the left creates multiple points of origin for the brown leaves beneath the flowers and the the second phiball on the right creates multiple points of origins for the small branches for the flowers. The branches are created with small horns and are followed by another phiball creating the points of origins for the petals of the flower. The latter are modelled using small white leaves in this model.

Figure 26: Armeria maritima photograph (photograph: Van Dobben), 3D model and model tool

The fourth plant which was modeled in Xfrog is Hippophae rhamnoides. Figure 27 shows a photograph of this plant on the left which was used to create the 3D model and the 3D model of the plant on the right. Figure 28 shows the Xfrog model of this 3D model. The model starts with a phiball which created all the points of origin for the branches. This long branche is modelled with the horn connected to the phiball. This brown horn is somewhat curved. The horn is then via a simple link continued by a green horn, a phiball and the leaves at the end of the branch. The other horn on the right is a multiple link horn, which takes care of all the branches. On these branches, leaves are attached on the end of the branch and between the end and the start of the branch. Due to the many branches and leaves of this plant and the abundance of this plant in the vegetation, the number of vertices on this plant has been reduced as much as possible. Rendering this plant costs a lot of graphical processing power and reducing the amount of vertices reduces the processing power necessary.

Figure 27: Hippophae rhamonides photograph (photograph: Van Dobben) and 3D model

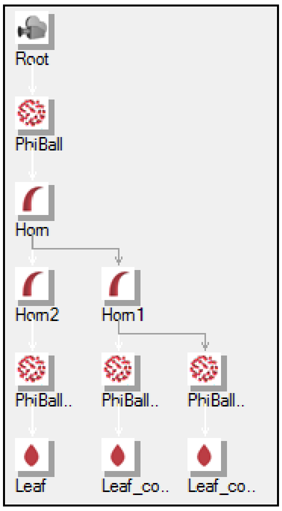


Figure 28: Hippophae rhamonides model tool

6.2.3 Conclusions on the 3D plant models

Both VisuAlea/PlantGL and Xfrog are capable of modelling plants. VisuAlea/PlantGL is very suitable if the different growth stages need to be modelled and if the modelling needs to be accurate. This will however need very precise L-systems code and if this code has to cover each growth stage and has to be accurate, this will require a lot of time to write, calibrate and validate. It is also possible to use the L-systems code more sketch based and this reduces the time necessary to create a plant. It would however be better to use Xfrog if the modelling is sketch based done, because Xfrog can achieve the same results in less time than it would take to write the L-systems code. Xfrog can also be used to 3D models for different growth stages, but this requires a new model for each growth stage.

Whether the created models are realistic enough will be tested in the expert test. The shape, colour, size of the six modelled plants will be discussed with the experts and it will be tested whether the plants can be recognized by them or not.

6.3 Linking the models together

The 3D visualisation was created with the VTerrain software. This is an open source software package which is capable of 3D visualisations of buildings, plants, infrastructure, elevation etc. The input (geo) data which was used to create the 3D vegetation visualisation are a digital elevation model, an aerial photograph of the research area, vegetation maps for each year the data was collected, point maps with all the data collection points for each year the data was collected and the database containing all the data from the four years the data was collected. These datasets and the adaptations or conversions which were done on these datasets will be discussed in a paragraph per dataset.

6.3.1 The Virtual Terrain Project

The used software package to create and show the 3D visualisation of the vegetation areas is Virtual Terrain Project. This open source package consists of three programs:

one for importing the 3D (plant) models (CManager), one for dataset conversion (VTBuilder) and one for the 3D visualisation (Enviro). All the 3D plant models were imported into CManager and used to create the common content file which Enviro needs.

6.3.2 The DEM

The DEM is an extract from the AHN (digital elevation model of The Netherlands). This DEM is a raster file with a 5 meter resolution and each cell contains an integer value with the height in centimeters. To use this file it had to be converted to a file with the height in meters. Therefore the map was converted in ArcMap with the tool Float to a map containing floating point height values in centimeters. This map has been divided by 100 to get the height in meters using the tool Divide.

The resulting map with the height in meters was then imported into VTBuilder. A small selection of the DEM was made with the map extends of the aerial photograph to reduce processing time (Figure 29). Then the Merge and Resample Elevation Tool was used on this selection (Figure 30). A new layer was created using the VTP .bt file format and all the sampling settings as shown in the figure were used to create this file. The resulting .bt file is then ready to be used in Enviro.

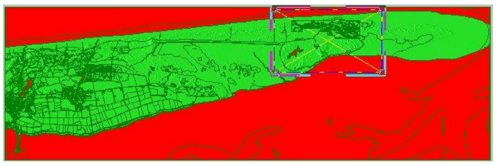


Figure 29: Selecting the DEM with the aerial photograph

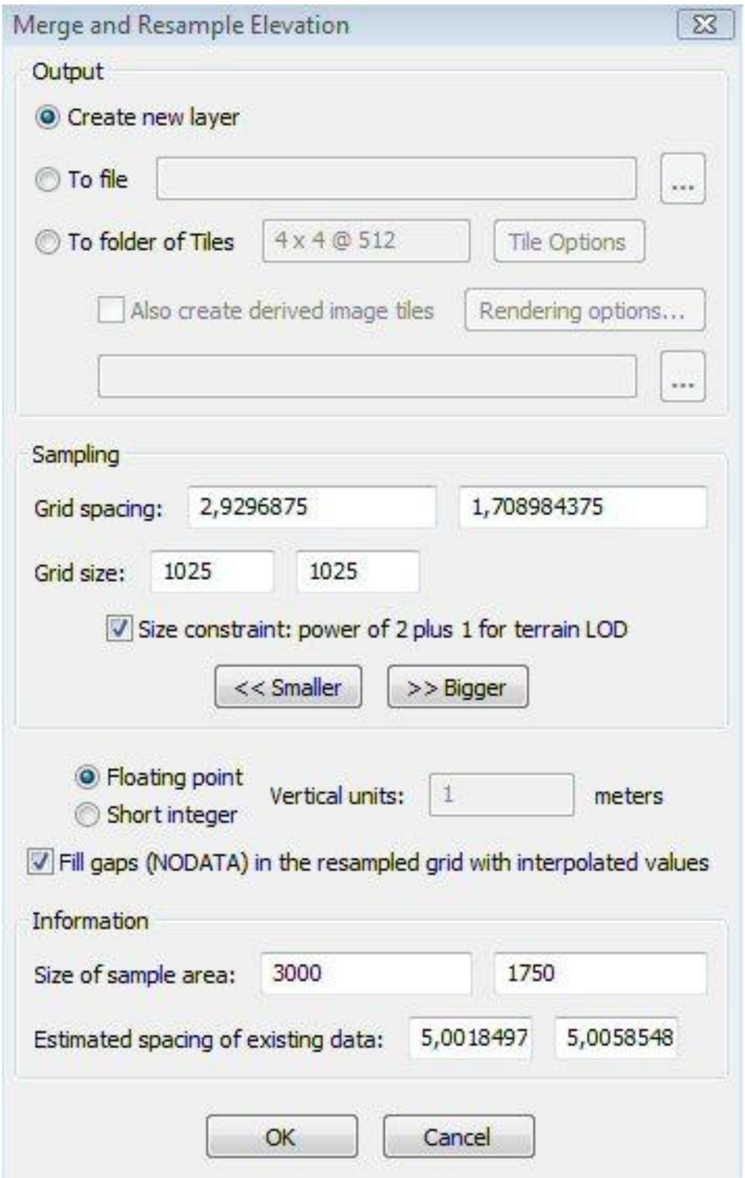


Figure 30: Converting the DEM in VTBuilder

6.3.3 The aerial photograph

The aerial photograph in TIFF format can directly be used in Enviro as long as the size of the photograph does not exceed the maximum size of the texture which can be loaded and used in the GPU of the computer. If the aerial photograph does exceed the texture size, it can be split into more textures, but this was not necessary here.

6.3.4 Generating the plant distributions

Generating a plant distribution for a vegetation area requires three input files: a list with all the species and their names and locations, a list with the so called bioregions containing the number of plants per square meter per plant per bioregion and a shape file containing areas numbered with their bioregion ID. Each file will be discussed in the following paragraphs. The species list is an xml file containing the name, location, type, size and height of each plant (see Appendix E for the contents of this file). The name should correspond with the plant name in the bioregions file (See Appendix F for the four bioregions files used in this case study). The location is the map and file which the 3D model or image contains. The type sets the kind of file which is used: image for billboards or true 3D models. The size seems only applicable when an image for a billboard is used. The height sets the maximum height each plant will grow.

The cover percentages for each plant for each vegetation type for each year were calculated in paragraph 5.1. This resulted in a table with a mean plant cover percentage for each plant. This mean value was divided by 100 and the comma was replaced by a period to make this value readable in the bioregions file of VTP.

However a major problem arises here, because the cover percentage is not the same as the number of plants per square meter. Although it would theoretically be possible to determine the cover of one 3D plant on a square meter and to calculate the number of plants it would take to cover the whole square meter with it, it is not possible in practice. This is because the plant modelling was done with the sketch based method and although they are look-a-likes of the real plants, they are not as accurate and concise as a real plant. The size or shape, which regulate the cover, have not been modelled with values for them based on statistical measurements from nature and therefore it is not possible to get a cover value which can be compared to cover values of natural plants. It was therefore decided to just continue and to use the cover percentages as number of plants per square meter. The values were only halved for the Hippophae rhamnoides, which is a rather large plant and thus easily reaches large cover percentage values. When this cover percentage is then used as the number of plants per square meter, the number of plants per square meter would be unnatural high. Halving the number was based on very rough estimations. Furthermore, one of the 3D modelled plants, Armeria Maritima, was recorded and in the database. It does however occur according to the descriptions that came with the photographs (see photos.mdb on the CD). In order to test the quality of this plant and, a fictional cover of 0.01 plants per square meter was added to vegetation type B.

The maps containing the four different vegetation areas for each year were given an extra integer field which should store a numerical code for the vegetation type. The original file stored the vegetation type as a character and this was not readable by VTBuilder. Therefore, the character was given a numerical code in this extra field and VTBuilder thus knows which vegetation is located where. These three files are then combined using the vegetation distribution tool in VTBuilder. The main options menu of this tool is show in Figure 31. By setting the grid spacing to 1 the number of plants per square meter will be correctly interpreted. No artificial scarcity is necessary and therefore, this value is set to 1. The biotype file and the specie files contain the necessary information about the species and densities and these fields are therefore not altered. The size is set to be from 75 to 100 percent of the maximum as specified in the species xml file. This 75 percent was chosen to give the plants some height differences so that they would not look the same in size. Setting the first value to 1 percent will result in some plants being barely visible. VTBuilder then makes a random distribution of all the plants in all the vegetation types and saves it to a special vegetation file which can be read by Enviro.

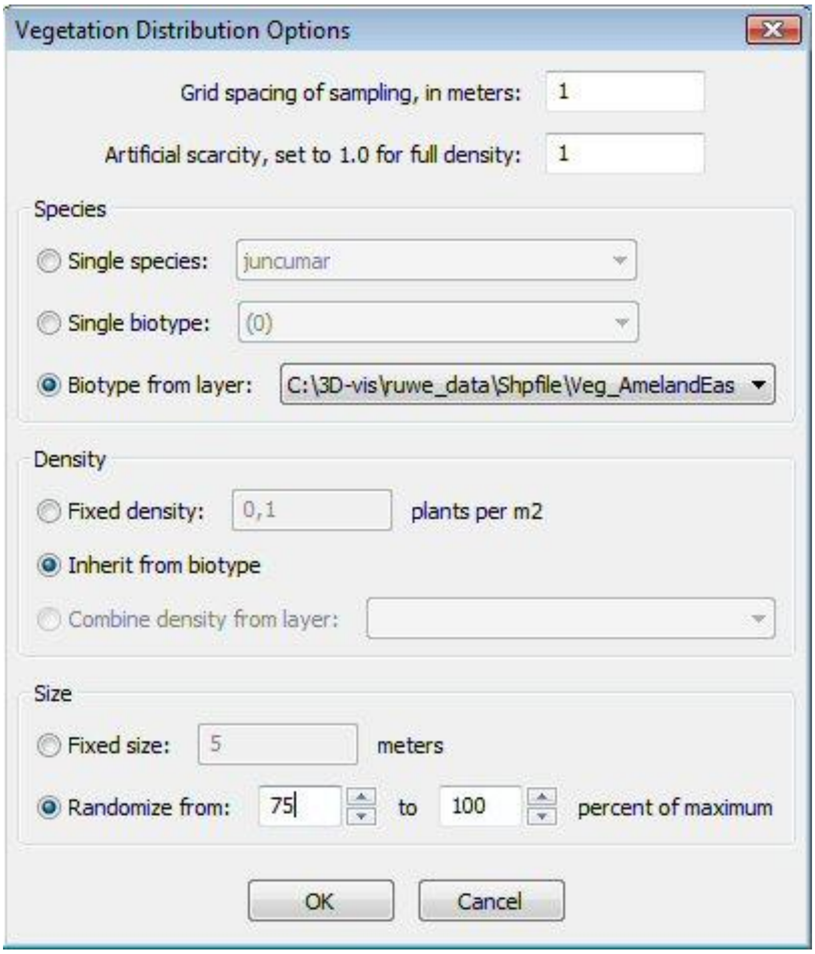


Figure 31: Vegetation distribution options menu

6.4 3D vegetation visualisation results

The digital elevation model, aerial photograph, 3D model content file and the vegetation distribution model are then loaded combined into an Enviro terrain file. Some extra settings can be done as well here. Most important setting is the visibility distance of the plants. Setting this distance too high will result in very low performance because it will cause Enviro to render too many plants. This setting depends very much on the capabilities of the graphical processing unit in the computer. The minimum height above ground and the near clipping distance were lowered to make it possible to look at plants from a very close distance. Furthermore, it is possible to add a background sky and an ocean plane. Both were added to give everything a more natural background. It is also possible to switch the overview map and the compass by default on, which was done as well. If this file is complete, it appears on the start screen of Enviro, which allows users to select their 3D visualisation in an easy way.

A white border around the research area was added to the 3D visualisation of the 2004 data. The purpose of this white border is to make it very easy to find the research area.

The effects of this will be tested in the expert test. The white border is generated by adding a shape file containing the research area as a polygon.

Figures 32 - 35 show the results in Enviro.

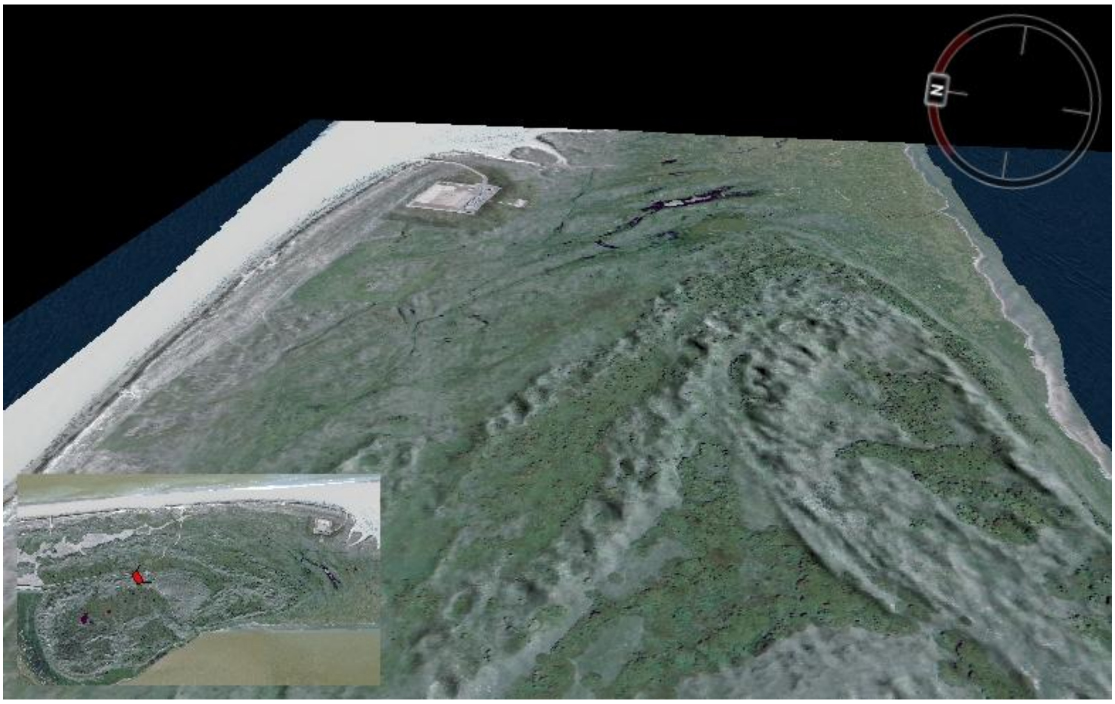


Figure 32: Overview of the area in Enviro

Figure 32 shows a screenshot taken from high above the area. The north arrow is in the top right corner and the overview map in the bottom left corner. The ocean plane is visible on both sides of the area and on the top and on the left, the end of the map is visible and no ocean plane is projected there. The plants are too far away to be visible. The square on east in the area is the NAM location where drilling for gas takes place.

Figure 33: Top down view on the vegetation in Enviro

Figure 33 shows a top down overview of the vegetation. The different plants are distributed over the area. The boundary between two vegetation types is visible: the left part of the area shows a distribution of many Potentilla anserina (the small green plants) while the right part of the area does not have these plants. The boundary is very sharp and the distribution of Potentilla anserina suddenly stops at the border.

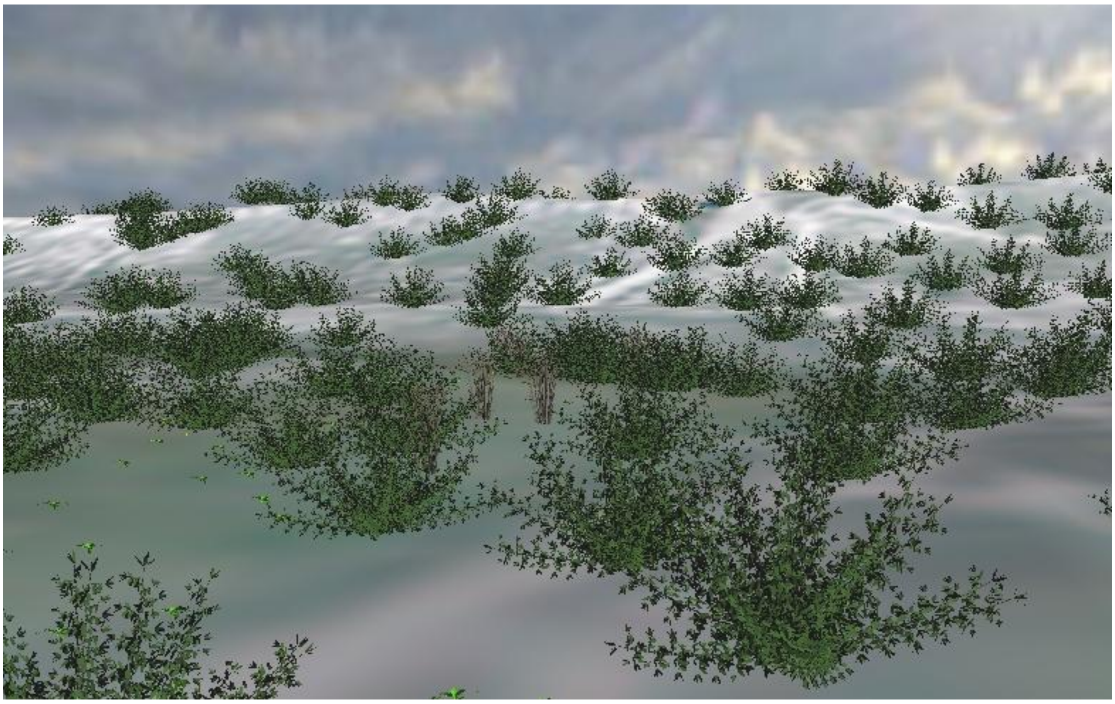


Figure 34: Typical view in Enviro

Figure 34 shows another view on the vegetation. The digital elevation model is clearly visible and together with the aerial photograph it forms a good model of a dune. The vegetation is distributed over the area regardless of this dune. Again, two vegetation types are visible and only the large Hippophae rhamnoides grows on the dunes in the back.

Figure 35 shows an artificial create image of all the plants available. Some plants were placed in Enviro at this specific location to show all the plants in one screenshot. There are some shadow effects visible in this picture. Triglochin maritima has a very dark brown colour while it has been modelled with a green colour for the stem.

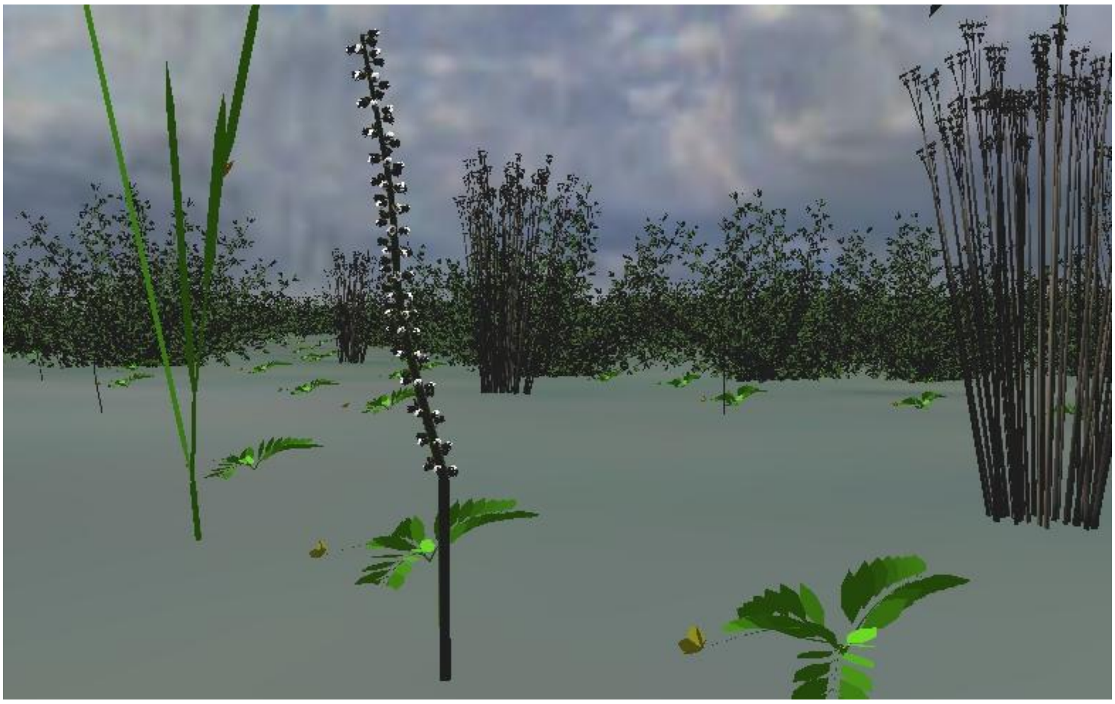


Figure 35: All the plants positioned together in Enviro

6.5 Conclusions on the Virtual Terrain Project Software

The Virtual Terrain Project software can be suitable for 3D vegetation visualisation. It is able to manage and load 3D models of plant species. Furthermore it offers the possibility to load a digital elevation model. It needs to be converted to a special format used by VTP and it might need some pre-processing in another GIS-package before it can be used, but the processes to do so are relative straightforward and easy. The aerial photograph could be loaded directly into Enviro, which makes it the easiest part to add. The software can also generate a vegetation distribution for different vegetation types and with multiple plant species based on the number of plants per square meter. This therefore requires information for each plant on the amount of plants per square meter per vegetation type. This information was however not available, because the input data contained the cover percentages of the plants. In order to continue with the case study, the cover percentages were used as if they were the number of plants per square meter. This results in a visualisation which can be run on modest hardware. However a very fast graphical processing unit would be of very good use to render more plants.

6.6 Conclusions on the case study

This case study has shown that it is possible to create a 3D visualisation of vegetation maps. The final 3D visualisation however is not a representation of the reality as it can be found in the research area, because the vegetation mapping output and 3D visualisation input did not match and a conversion was not possible within the limited time of this research. In order to continue this research, it was decided to use the output as it was matching the necessary input, but this introduced an enormous error in the data. Whether the 3D visualisation of the vegetation map has been successful apart from this input-output problem will be tested in the expert test.

It has also shown that the original work process to come to a 3D visualisation was not complete. The vegetation descriptions were missing, a selection process of the plants which should be 3D modelled should have been added and the geographic data which is used in the 3D visualisation was not modelled. The missing vegetation descriptions in the work process made it possible to include the use of scenarios in the methodology. But the changing plant abundance of each vegetation type made it impossible to create scenarios, because there was no information available about how the plant abundance would be in the future.

7 3D visualisation: the expert opinion

In order to evaluate the results of the 3D vegetation visualisation, a small expert test was set up. Two biologists who were also involved in the vegetation mapping of the case study were willing to test the 3D visualisation and to answer questions about the simulation quality and usability. The following three paragraphs will discuss the evaluation criteria, the set up of the expert test and the results from the expert test.

7.1 3D vegetation visualisation evaluation criteria

The expert opinion has been researched by using a questionnaire. The questions in this questionnaire are derived from literature about 3D visualisation evaluation and usability evaluation. First, the literature will be discussed and then the questions developed from the literature will be presented.

	Appleyard's criteria	*Sheppard's criteria*
Interesting/engaging	√	√
Comprehensible/visually clear	√	√
Accurate	√	√
Realistic	√	
Representative		√
Evaluatable	√	
Legitimate		√

Table 4: Comparison between Appleyard's and Sheppard's criteria for the evaluation of simulation quality (Mahdjoubi & Wiltshire, 2001)

The article of Mahdjoubi and Wiltshire (Mahdjoubi & Wiltshire, 2001) tries to come to a framework to guide research into the evaluation of computer generated visual simulations. They focus on simulation quality and come up with several criteria for this based on the work of Appleyard (1977) and Sheppard (1989). Their criteria have been listed in table Table 4. The criteria will be discussed in relation to the Ameland case study briefly.

7.1.1 Evaluation criterion "Interesting/engaging"

A good 3D visualisation should raise interest by the viewer. Furthermore, if it is used in a decision making process, it should involve the people using the visualisation more into this decision making process. To test whether the 3D visualisation was interesting to the user, the questions will ask how interesting the 3D visualisation is (Mahdjoubi & Wiltshire, 2001).

7.1.2 Evaluation criterion "Comprehensible/visually clear"

Whether a visualisation is comprehensible or clear depends largely on the knowledge of the viewer. Abstract graphs and figures can be comprehensible for experts, but not for lay people. So therefore the comprehensibleness of the visualisation depends on the level of knowledge of audience the visualisation is targeted at (Mahdjoubi & Wiltshire, 2001). To test this comprehensibleness, a number of questions about the visualisation can be asked and compared with the goal and subject of the visualisation as stated by the creator. If these are the same, it can be concluded that the users have understood the visualisation. In this expert test however, it will be difficult to test this, because the people testing it have already been working with the data and they can use the knowledge they already have to interpret the visualisation. It will therefore be compared with the more abstract vegetation maps.

7.1.3 Evaluation criterion "Accurate"

The accuracy of a 3D visualisation is the way the 3D visualisation reflects the relevant features in the real world. There can be two ways of accuracy distinguished: apparent realism and actual realism. The first one can be explained as the emulation of real world features which is convinces the viewer that the simulation would be possible in a real life situation. The actual realism is about the equivalence to the real world situation (Mahdjoubi & Wiltshire, 2001). It is possible to test the apparent realism, because a 3D visualisation was created based upon data sets derived from the real world. It was however not the goal to put every plant in its exact position where it could be found in the Ameland research area. Actual realism is therefore not achieved and can therefore also not be tested. The apparent realism however can very well be tested by the experts because they know the situation in the research area. The questions will therefore ask if the distribution of the plants is realistic or not.

7.1.4 Evaluation criterion "Realistic"

The previous criterion used the term realism in relation to the emulation of real world features. The difference with the criterion "Realistic" is that this realism is about the visual realism. A 3D visualisation does not necessarily have to be photorealistic. Present technologies still not allow doing so, although it is more and more possible to achieve near photorealism. A realistic 3D visualisation should *contain the appropriate information to support the viewers in the tasks in which they are engaged* (Mahdjoubi & Wiltshire, 2001).

For this 3D vegetation visualisation, it will be tested whether the biologists can relate the 3D plant models to the real plant species and whether they can recognize the different vegetation types. Furthermore, there will be questions about the realism of the size, shape and colours used for the plants. A photograph of a cloudy sky has been added to the visualisation, which has in fact nothing to do with the vegetation visualisation and there will be questioned whether this supports or distracts the user from his task.

7.1.5 Evaluation criterion "Representative"

The visualisations of new development projects are sometimes subject to the process of idealisation. All objects look new and shiny, people seem to be happy and the sun is shining. It becomes more a process of 'selling' then of 'faithfully portraying' and this lowers the credibility of a simulation (Mahdjoubi & Wiltshire, 2001). However, the case study here is not a new property development, but a vegetation visualisation and therefore there is no need to manipulate the visualisation. It is therefore assumed that the visualisation is representative and this will not be tested.

7.1.6 Evaluation criteria "Evaluatable" and "Legitimate"

The evaluation criteria evaluatable and legitimate refer to process of checking whether the visualisation corresponds to reality and how users on this base can use the visualisation for their own purposes (Mahdjoubi & Wiltshire, 2001). Part of this can be realised by describing the process of creating the visualisation and all the steps and decisions to come to this visualisation. This will be tested by checking whether this will be understood.

7.1.7 Usability

The usability of the visualisation is not mentioned by Mahdjoubi and Wiltshire as a criterion for the visualisation. With some logic it could be derived from the "interesting" criterion: when a visualisation is hardly useable, then it would be not very interesting because one has to learn the controls first before one can see the benefits. This logic however is not very convincing to put the usability as a part of the interesting criterion. Instead it will be added as another criterion to evaluate the simulation quality.

The usability of software or in this case, the software which runs the 3D vegetation visualisation, can be divided into three characteristics: is it understandable, can it be learned and can it be operated. There is some overlap with the comprehensible criterion here and this will therefore not be tested again with the usability (Bevan, 1999). For a 3D visualisation, navigating through the 3D world is very important. The user should easily fly around and be able to inspect everything he or she wants. There are a number of different control implementations around and even specialized hardware to help the user navigating around. It is therefore necessary to test whether the users can navigate easy in the 3D visualisation to cover the operation characteristic. The learning characteristic will be tested by asking how difficult it was to learn to operate the 3D visualisation software. Because very few people do have a 3D mouse, it will also be tested how a regular mouse performs in the application and which one is better in their opinion.

7.1.8 Questionnaire

The questionnaire in appendix C is based upon the evaluation criteria from the previous paragraphs. Most of the questions are formulated as statements and use a likert scale to rate the agreement of the respondent with. The possible answers are: Strongly Agree, Agree, Neither agree nor disagree, Disagree, Strongly Disagree. Other questions are open, because it will sometimes be necessary to explain the choice for an answer on a statement or it is necessary to let them describe a problem.

The experts will start with the 2001 visualisation. This visualisation does not have many questions and serves also as a sort of a training visualisation for the navigation. The 2004, 2006 and 2008 3D visualisations will follow after each other and some questions will be repeated for all the four years and other questions will be asked once in a specific year or after all the 3D visualisations have been visited. The questions in appendix C are sorted per topic, but questionnaire that will be presented to the experts will be chronologically sorted. The italic text explains the moment(s) where the question will be asked. The green text contains the instructions which are given to get the information required to answer a question. The type of answer is stated in the column on the right.

7.2 Test setup and participants

The expert test was held with dr. Han van Dobben and ing. Rik Huiskes. Han van Dobben is a senior ecology researcher at Alterra and he has done a lot of research in the Ameland research area. Rik Huiskes is a DLO-HBO-researcher at Alterra. Both therefore have expert knowledge about the vegetation in the research area can use it to evaluate the 3D visualisation.

The expert test was held in a session of two hours. There were two laptops available for the experts with a fast CPU and GPU. During these two hours, the experts used the 3D visualisation and answered the statements and the questions in the questionnaire. During this part of the expert test, Han and Rik made a lot of oral comments and these were written down and structured later on to form the test report. They also communicated with each other and showed each other remarkable aspects of the 3D visualisation. The discussion afterwards was used to discuss the comments which they made during the test more in depth. Notes were taken from this discussion and these were also put into the report. The report and the questionnaires were send to Han and Rik in order to let them correct eventual errors and add additional information where necessary. The corrected report and their questionnaires can be found in appendix D.

7.3 Test results

The results on the evaluation criteria will be discussed in the coming paragraphs. The first part of the paragraph will discuss the results from the questionnaire and the second part will contain the discussion which took place with the experts after the tests were done. Each evaluation criteria will be given a score: a “-“ when it the case study has been unsuccessful in meeting the criterion, a “+/-“ when the case study has partially been successful in meeting the criterion and a “+” when the case study has been successful in meeting the criterion. These scores will be placed in a table at the overall score. From the discussion another idea for 3D visualisation of vegetation emerged, which is placed at the end of this chapter.

7.3.1 Test results on “Interesting/engaging”

The 3D visualisation has been successful in raising and keeping the interest by the viewer. Han strongly agreed on all the years that it was interesting to move around and Rik agreed all the years that it was interesting to move around. Furthermore, both Han and Rik agreed on all the years that it was interesting to see the plants in detail. The vegetation areas are somewhat less interesting, because Han and Rik both rated 3 out of the 4 years interesting. Rik however thought that discovering the 2004 vegetation areas was not interesting and Han could not agree or disagree for 2008 that it was interesting to discover the vegetation areas. Both Han and Rik were curious when the visualisations of 2004, 2006 and 2008 were loading. On these results it can be concluded that all the visualisations were interesting and that this remained the whole session. Overall, this criterion is rated with a + .

7.3.2 Evaluation criterion “Comprehensible/visually clear”

The 3D visualisation was not better to understand compared to the rather abstract vegetation maps. Both agree that the vegetation maps give a better overview of the distribution of the different vegetation areas compared with the 3D visualisation. They also agree that the vegetation map gives a better overview of the abundance and distribution of the plant species. They agree that the maps give a better overview of the vegetation changes over the years compared to the 3D visualisation. They therefore don't prefer the 3D visualisation above the vegetation map. Rik however points out in a side note that his special interest in vegetation science helps him in understanding the more abstract map. The cause of this relative low comprehensibility is likely to be found in the realism of this 3D visualisation. They pointed out that it was somewhat confusing that only plants within 75 meters were visible and that the visualisation the way it was now did not fit to their analysis method which they use when doing field work. From the discussion which followed after the expert test it became clear that when Han or Rik enter the field for research, the first thing they do is to look at the vegetation structure, grain size and colours. This gives them a good idea of which vegetation type is where and also an idea of which parts of the whole area will be interesting to investigate further. In fact they create a vegetation map in their mind when they overview the whole area. The structure, grain size and colour are determined by the generic and abundant plant species and not by the rare species. The rare species are only discovered when they look to the plants down by their feet if they investigate a vegetation type in more detail. The current 3D visualisation does not suit their method of analysis, because the structure of the vegetation becomes not very clear and because there are not enough differences in colour. This is the reason why the different vegetation types do not have specific characteristics in their opinion. It is also necessary to set the visibility distance of the plants at 300 meters, because it makes it possible to look at the vegetation in order to see the structure, grain size and colour of the vegetation. The performance drop in the software is less important than the visibility distance. As they point out, they will get accustomed to the low frame rates as they are accustomed to other slow working software, like a text processor with large documents. However, if they want to use it as a communication mean, they will need performance as well. Figure 36 shows what the difference is between a visibility distance of 100 meters and a visibility distance of 500 meters. With the 100 meters setting, it is not possible to see the structure of the vegetation further away, but with the 500 meters setting, this is possible. Overall, this criterion is rated with a - .

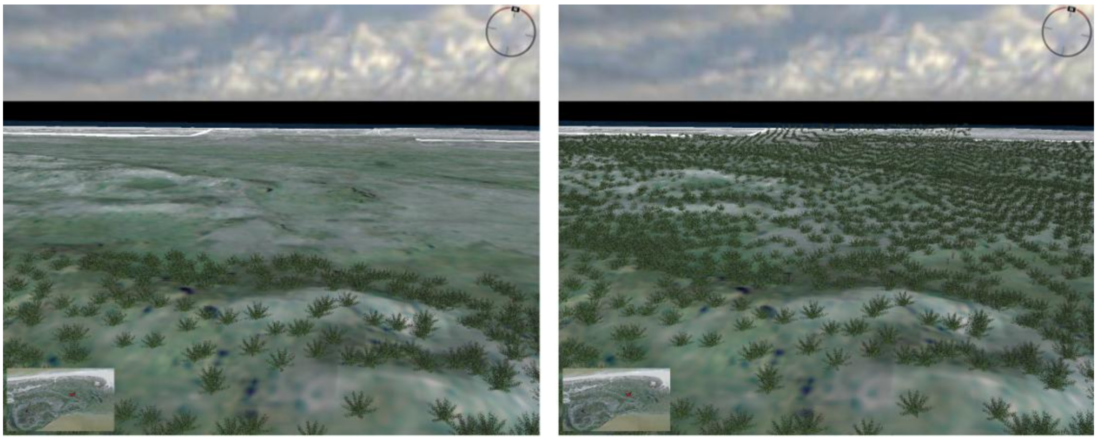


Figure 36: Differing visibility distances. The image on the left has a visibility distance of 100m and the image on the right a visibility distance of 500m. Both were made at the same camera location, height and direction. The plants in the image on the right are visible until the research area boundary.

7.3.3 Evaluation criterion "Accurate"

The opinions about the apparent realism are mixed. Han agrees that the distribution of the plants over the research area or the vegetation areas is comparable to the real situation in the Ameland research area, while Rik disagrees with this. Han notes that it is not realistic that Hippophae rhamonides is present nearly everywhere, while other species are usually inconspicuous. In his opinion, this can be improved by adding more species and more variation in the individual size of the plants. Rik also notes that there should a connection between the distribution on the one hand and the size and variation of species on the other hand. Furthermore, the Hippophae rhamonides growing on or near the beach is far from reality.

From the discussion it became clear that the Hippophae rhamonides is too dominant; there should be more grassy vegetation with more grasses and thistles. Furthermore, many plants tend to cluster and this is not taken care of in the current 3D visualisation. The patterns which can be seen in the 3D visualisation can also be found in nature, due to nature management measures or plant species specific distribution characteristics, but are certainly not standard for all plants. The patterns in the visualisation are therefore not representing a natural distribution. Furthermore, there is not taken care of the borders between the different vegetation areas. These borders can be fuzzy, but this does not necessarily have to be. However, in this 3D visualisation all the borders are clearly visible.

One of the relevant features in the real world is the soil cover by grasses and dead plant materials. These two were not included in this 3D vegetation visualisation. A question raised later on in the discussion was: What is an individual plant? The answer to this question is difficult, because the cover of for instance grass can easily be estimated by a biologist, because he does not have to take into account the individual grass plant when the estimating its abundance as a percentage. It becomes a problem when grass is to be modelled in 3D, because it is then necessary to know what an individual grass plant is. Furthermore, modelling the abundance of the grass by the number of plants per square meter is impossible if only the cover percentage of an unknown amount of individual grass plants is known. It is possible to use photographs of the ground in the 3D visualisation to improve realism and to avoid the problems with grass individuals, but this can only be done when the grass is decoupled from the vegetation mapping and vegetation data. This subject is also related to the dead plant materials. Dead plant materials can also cover large parts of the ground, for instance forests have most of the ground covered by dead leaves, but they are in general not included in the datasets of vegetation mapping. The vegetation succession modelling (SMART2SUMO) does include dead plant materials in the model and it offers therefore the possibility to 3D model these dead plant materials. There are therefore two reasons for modelling dead plant materials: because it is part of the model or because it is likely to improve the realism of the 3D visualisation. It can be modelled the simple way using photographs, but there could be reasons to model dead plant materials more sophisticated. Modelling of grasses and dead plant materials will therefore improve the apparent realism of a vegetation visualisation. Overall, this criterion is rated with a +/-.

7.3.4 Evaluation criterion "Realistic"

The 3D visualisation is not successful in visualising distinctive vegetation types. The four different vegetation types were only one time judged to be distinctive by Rik and Han could only disagree or at most not agree nor disagree that the vegetation types were distinctive. This low distinctiveness of the vegetation types is likely to be one of the causes for the low comprehensibility, because when it is not possible to discern the different vegetation types, it is also not possible to discern changes within a vegetation type over the years or to get a good overview of the spatial distribution of the different vegetation types.

The 3D visualisation was however partially successful in visualising the plant species. Although they could not recognize all the plants from the start, it was possible to recognize them later on. The most notable plant which was not recognized was Hippophae rhamonides. The six plants will each be discussed:

- Hippophae rhamonides was not recognizable, because the height variation was too low, the colour was green instead of grey and the shape was not realistic. Furthermore, the leaves were too large and the typical spikes which the plant has were not modelled.
- Potentilla Anserina was recognizable and did not receive any comments.
- Triglochin maritima was also recognizable, but due to its rareness, it was hard to find the plant and this plant has also missing lower parts.
- Scirpus maximus was recognizable and did not receive any further comments.
- Juncus maritimus was hard to recognize, because the colour was brown, but should have been green instead.
- Armeria maritima was not recognized by Rik, because the white-pink colour of the flower was lost due to shading effects in the software. This is also a plant which has more leaves near the ground and these were not modelled. The size of the model was also too large.

On this basis, it can be concluded that most of the plants were recognized, but that two of the six modelled plants can be improved to achieve better realism and that two of the six need drastic improvements, so that they can be recognized by the biologists.

The photograph of the clouded sky improves the feeling of realism and does not distract them from their tasks and although it has nothing with the vegetation to do, it is a good addition to the 3D visualisation.

The discussion after the test gave some more explanation to their remarks. The first thing is that the plants have different variations in size: the Hippophae rhamonides varies from very small plants of about 10 centimeters to large plants of more than 1 metre. The Potentilla Anserina on the other side does hardly vary in size. This is insufficient modelled by VTBuilder, because it can only model the height differences for all the plants together. The height of all the plants varies from 75% to 100% of the original 3D model height of the plant, but for Hippophae rhamonides (1 metre standard size in the 3D model), this should be more like from 10% to 150% and for Potentilla Anserina about 90% - 100%. It can be solved by importing more models with different sizes for the same plant species. Furthermore, the realism of the plants can be improved by adding more variation in the plant models. There are many shapes and sizes found in nature and it would be better if this was also done in the 3D visualisation. Overall, this criterion is rated with a - .

7.3.5 Evaluation criteria "Evaluatable" and "Legitimate"

Before the 3D visualisations were presented, a short explanation was given about the working process to come to this 3D visualisation. Han and Rik agree that they understand how the 3D visualisation was created from the vegetation maps. On this basis, it can be concluded that the 3D visualisation is evaluatable. They note that the 3D visualisation as it now is needs more species, a more realistic distribution and more realistic colours.

From the discussion afterwards, it became clear that there has been made an important error in the 3D visualisation process. The choice of plants to be visualised depended on the available photographs of the plants. It would be better to make a selection for the 3D models based upon the recordings dataset. The species that determine the large overview by their abundance, size, colour or grain should be selected to be 3D modelled and visualised. Unknown is the amount of species which should be 3D modelled per vegetation type to get distinctive vegetation types, but for this visualisation it was clear that the amount of 3D modelled species was too low. Overall, this criterion is rated with a + .

7.3.6 Usability

It was assumed, based on positive experiences with the 3D Spacenavigator earlier this research that the 3D mouse would give better usability compared with the regular mouse navigation implementations. The test was therefore mostly done with this 3D mouse and only 2008 was explored with the regular mouse. This assumption however was wrong, because both Han and Rik prefer the regular mouse above the 3D mouse. Han disagrees that it is easy to navigate around in the 3D visualisation. He was not able to reach all the positions and locations he wanted. He disagrees that it is easy to move forward and backward or sideward. He agrees that it was possible to get close enough to the plants, to move up and down and to tilt. He therefore disagrees that it is easy to master the capabilities of the 3D mouse. The regular mouse with the panoramic flyer implementation in Enviro is better to master, because he cannot agree or disagree with that. He cannot agree or disagree that it is easy to navigate in the 3D environment, but agrees that it is easy to move up and down, left and right, forward and backward, to tilt forward and backward and that the regular mouse is intuitive to work with. Rik on the other hand had fewer difficulties in navigating around with both the 3D mouse and the regular mouse. He agrees mostly agrees that both the 3D mouse and the regular mouse are easy to use. He cannot agree or disagree that it is easy to navigate with the 3D mouse whereas he does agree with the statement that it is easy to navigate with the regular mouse. He therefore notes that *the regular mouse was better, but in to long run, the 3D mouse would be better.* It is hard to draw conclusions from this, because they both had no experiences with the 3D mouse before. Furthermore, the 3D mouse Rik used was the large model and the 3D mouse Han used was the small mobile one. It is possible that this mobile 3D mouse is harder to use than the large model and that the difference between Han and Rik is caused by this. It is also possible that Rik has more talent for operating the 3D mouse. However, the panoramic flyer mouse implementation is sufficient for navigating around and therefore a good alternative if the user has problems with a 3D mouse or when no 3D mouse is available. Because the panoramic flyer can always be used, it can be concluded that there will always be a sufficient navigation device available and the controls are therefore usable.

The overview map has been helpful. The north arrow and the white border around the vegetation area were only helpful to one of the experts. Overall, this criterion is rated with a + .

7.3.7 Overall

Both see possibilities of this 3D visualisation for their research. More abstract map layers such as ground water levels, chances on sea water intrusion, number of days the area is flooded are desired to be (optionally) visualised in the 3D visualisation. Rik also wants to see a simple topographic map in case a large area is to be visualised. Han and Rik both want to see model output of nature changes over time to be 3D visualised. Rik mentions the natureplanner here, which is the combination of SMART2/SUMO and MOVE. Both could not agree on the statement that this is a successful visualisation of vegetation. Therefore, the overall score is a minus. This minus is their opinion about the 3D visualisation and not the total of all the criteria summed up. Table 5 shows scores of all the evaluation criteria. It becomes clear from this table that the 3D visualisation was not realistic and not visually clear and these are the main reason why the 3D visualisation was unsuccessful.

Evaluation criteria	**Successful**
Interesting/engaging	+
Comprehensible/visually clear	-
Accurate	+/-
Realistic	-
Evaluatable and Legitimate	+
Usability	+
Overall	**-**

Table 5: Overview of the score results of the 3D visualisation of the case study

7.3.8 Another method for modelling the individual plant distribution

The vegetation maps can also be bypassed to model the abundance of plant species. There is a large database containing the response of plant species to the abiotic characteristics. If maps containing the abiotic circumstances in an area are overlaid, it should theoretically be possible to calculate the chance of finding the specie at a specified place. How this chance should be translated to the number of plants per square meter or the cover percentage is unclear. There is the possibility that the possibility of a plant occurrence equals to the cover percentage, which makes it possible to make a computer generated distribution with 3D models of plants with a reality based cover percentage. The major advantage is that it will offer the opportunity to model the distribution of species for the future using abiotic changes within scenarios. This solves the problem that existed in this case study, because it was planned to use scenarios in this 3D visualisation too, but uncertainty about the changes over the years in plant abundance within a vegetation type made this impossible. Creating a plant distribution this way largely depends on the availability of response data for the plants growing in the area one wants to model and on the availability of maps with information about the abiotic circumstances. This method shows some similarities with Agent Based Modelling or Cellular Automata, because these modelling techniques can also take into account the abiotic circumstances. These models do however also make the final distribution, which is not necessarily the case here.

8 Discussion

The results from this research will be discussed here. The first paragraph will discuss the 3D visualisation process as it was described in the introduction of this thesis. The other four paragraphs will discuss the results for the sub questions 2 – 5. Because the input vegetation map in the case study was used as it was delivered no discussion on this map is necessary and the problems and results which resulted from using this dataset will therefore be concluded on in the conclusion.

8.1 Amount of and selection plants to be modelled

There has been no proper selection process for the plants which should be modelled in 3D. A small set of photographs of some plants was initially available and a more or less random selection of these plants has been 3D modelled. As it turned out, the amount of the 3D models was too low and the choices for the plants which were modelled were sometimes wrong. As discussed in 7.3.2, the biologists make an overview map of the vegetation in their mind when they do field research. They tried to apply this method also in the 3D visualisation, but failed to analyse the vegetation in this way, because there were no structure, colour differences or grain differences visible. There will have to be more species available as a 3D model per vegetation type to model the structure, colour differences and grain differences between the vegetation types. Unknown however is the amount of species which have to be 3D modelled and to be placed in the 3D visualisation to model the specific structure, colour and grain for a vegetation type. Table 1 shows that Triglochin maritime is a very rare species and it covers a very low area. It therefore does not contribute to the structure, colour or grain of a vegetation type. It should not have been selected for this case study. Instead, a plant which does contribute to the vegetation colour, grain or structure should have been selected. These rare species should only been have modelled and added to the vegetation if the goal is to model and communicate the abundance of this rare species over the years. It is therefore necessary to make a selection of all plant species before the 3D modelling of the plants starts. The selection criteria will be whether a plants species contributes to the colour, grain or structure of a vegetation type. This selection should then be 3D modelled and 3D visualised. The 3D visualisation should then be compared with the real situation to test whether the grain, colour and structure in the 3D visualisation matches with the grain, colour and structure from reality. The schematic overview of the 3D vegetation visualisation process as it was first presented in the introduction is therefore adapted with the plant selecting process. Figure 16 shows this modified visualisation process.

8.2 The plant distribution

A flaw in the distribution is the patterns in which the plants tend to grow. Figure 37 shows that the Hippophae rhamonides tends to be distributed in lines or V-shapes. This becomes well visible because this is a large plant and its abundance is very high.

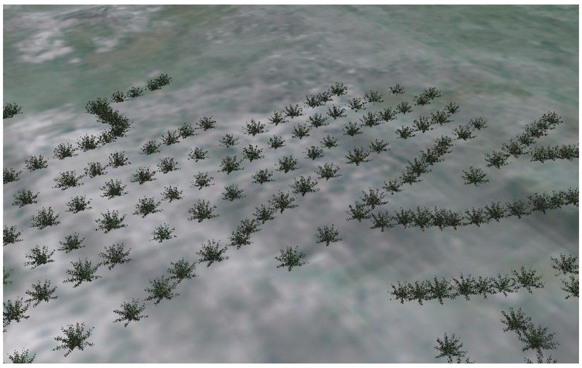


Figure 37: Patterns in the plant distribution with a 1 meter grid spacing

To test whether this problems comes from the chosen distribution settings for the grid, the distribution has been made again with a 0,5 meter grid spacing and a 0,1 meter grid spacing. The 0,5 meter grid spacing offers 4 times more possible locations where this plant could be placed and the 0,1 meter grid spacing offers 100 times more possible locations. Setting the grid spacing above 1 results in too less locations for the plants and is therefore not an option. All other settings, such as the scarcity, remained the same with these new distributions. The 3D visualisation of these new distributions is visible in figure 40 and 41 and it becomes clear that setting the grid spacing to 0,5 or 0,1 does not solve this problem.

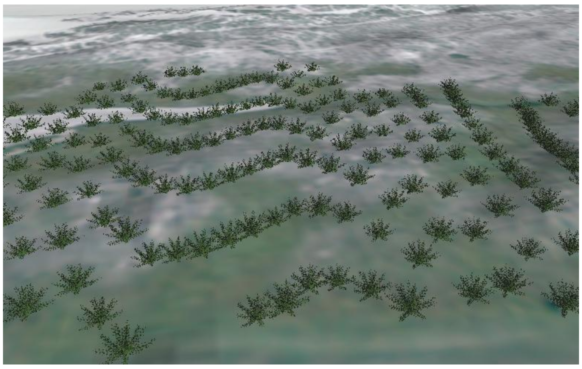


Figure 38: Patterns in the plant distribution with a 0,5 meter grid spacing

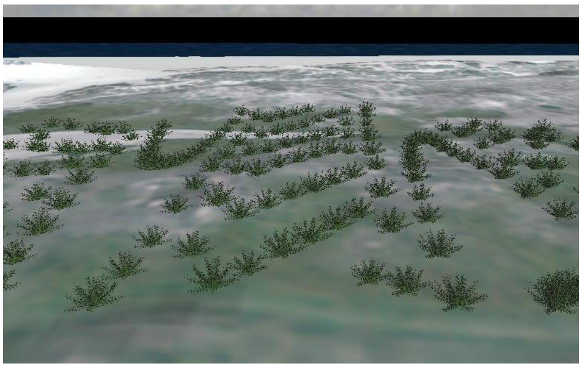


Figure 39: Patterns in the plant distribution with a 0,1 meter grid spacing

From the discussion after the expert test, it became clear that some plant species do grow in patterns for various reasons, but that these patterns are not usual for the 3D modelled plants. From this discussion also became clear that a pattern which can often be seen with many plants is clustering. This clustering pattern is however not modelled in the distribution model. A possible method to model is the deformation kernel. The deformation kernel can be described as the impact on a field of values that characterises the probability of finding a plant species at this location. The deformation kernel can raise or lower this probability at the locations of an existing plant and with this process, clustering can be regulated. Figure 40 shows some variations of these deformation kernels (Lane, 2002). Variant d of the deformation kernels in the figure would be very suitable to model the clustering: the inhibitory effect very close to the plant will avoid that plants will grow too close and the promotional effect will take care of the clustering. It would require a map with the probability of plant occurrence to model these kernel deformations upon and it would therefore be a good addition to the plant distribution method based on plant species response to abiotic circumstances.

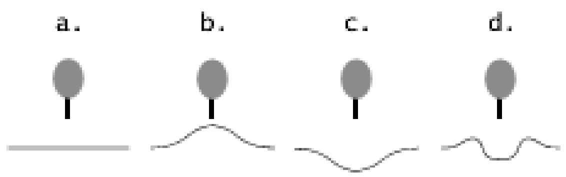


Figure 40: Examples of deformation kernels: a) kernel that has no effect on the neighbouring plants ,b) kernel that has a promotional effect ,c) kernel that has an inhibitory effect ,d) kernel that has an inhibitory short-range effect and promotional longer-range effect (Lane, 2002)

8.3 The 3D plant models

Some of the plants were not recognized during the expert test. The causes for this are that the plants had the wrong colour or that the shape and size were not right. The reasons for these wrong colours are the used software and a wrong interpretation of the plant during the modelling.

Enviro, the 3D visualisation program, is adding shadow effects to the plants. Theoretically, this should make the visualisation more realistic, but in reality, the effect is that the plants become very dark when they're viewed from certain positions. Figure 41 shows how this shadow is applied in Enviro and how the colours in the 3D visualisation of this plant deviate from the colours as they were modelled in Xfrog. The plant behind Triglochin maritima, Potentilla Anserina also has some variation in the colours of the leaves, but this is not as extreme as it is with Triglochin maritima and it was therefore without problems recognized during the expert test.

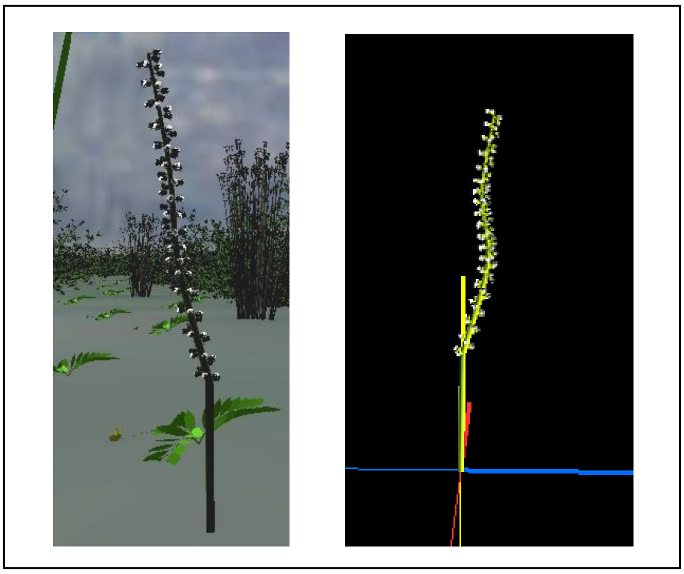


Figure 41: Shadow effects degrade the colours of the plants. The image on the left shows the colour of Triglochin maritima in the 3D visualisation and the image on the right the colours of this plant as it was modelled

The other reason why the colours where wrong according to the experts was because the colours where not well translated into the models. The Hippophae rhamonides therefore got green leaves, which should be grey in reality. This can be solved by spending more time on picking the colour for the leaves.

Another conclusion from the expert test is that the shapes of the plants were not properly modelled. The lower parts of some of the herbs were missing and the shape of Hippophae rhamonides was also insufficient modelled. The reason for this is presumably that the photographs were mostly taken from aside the plants. Exception to this was the photograph of Potentilla anserina, which was taken from above and which did get the lower parts modelled as well. It would therefore be better to have more photographs from different angles of the plants available and, if possible, more photographs of different plants of the same species.

8.4 Linking the models together

A major problem which made it impossible to create an apparent realistic distribution is the cover percentages output from the vegetation data and the number of plants per square meter input for VTP. Theoretically, a transition can be made between these two, because the mean plant cover percentage divided by the cover percentage of a single 3D plant model of a square meter will result in the number of plants per square meter. However the 3D models of the plants were sketch based created. They lack the accuracy, because there were no parameters used to create these plants which are derived from field measurements on these plants. Estimating the cover percentage of a 3D model of a plant would therefore not result in an accurate cover percentage, but in a cover percentage which is flawed by all the assumptions made in the sketch based 3D modelling process. For instance these assumptions are the shape of the leave, size of the leave, shape of the plant etc. Most of the plants were created using a photograph taken from aside of the plant and to make a more accurate plant in terms of its cover, it would be better to have a photograph taken from above the plant to model its cover. It was therefore hardly possible to calculate or estimate the cover percentage of a 3D single plant model. Furthermore, the expert test proved that the modelling of plants was not sufficient to use the 3D plant models for these calculations, because some herbs were missing the lower parts of the plants, notably leaves. Adding leaves would increase the cover and a calculation without these leaves would therefore have resulted in a too high number of plants per square meter. The choice therefore was to have a flawed number of plants per square meter by using the cover percentages as the number of plants per square meter or by calculating the number of plants per square meter by using 3D models which lack the accuracy to do so. The first option would save a lot of time and it was therefore decided to use the cover percentages as the number of plants per square meter. The distribution of the plants is therefore not based on reality and the 3D visualisation of the vegetation is also not based on reality. On this basis it can be concluded that vegetation maps with cover percentages are not suitable for 3D visualisation when sketch based plant models are used. The 3D visualisation created with it is, although not based on reality, still more or less suitable to test the different aspects of it with the experts and it was therefore decided to continue with this flawed distribution.

Another problem is the variations in the structure of the vegetation from year to year. The definition of vegetation in the introduction assumed there was no variation in the structure of the vegetation over the years. The distribution of a mixture of plants was to be specific for a vegetation type. This assumption however was wrong, because the data from the vegetation mapping process shows clearly that the abundance of certain species varies from year to year within the vegetation type. The result of this was that the cover percentages of each plant species in each vegetation type had to be calculated for each year. The consequence is that it will be impossible to make scenarios for future development of vegetation with this kind of vegetation map, because it is not known what the composition of the future vegetation types will be. Creating scenarios for future vegetation development therefore requires either another scenario for vegetation structure development or a kind of a mean vegetation structure which can be used for the scenarios. It was therefore not possible to make one or more 3D vegetation visualisations of future vegetation development as it was proposed in the methodology.

8.5 The expert test

The questionnaire was filled out by only two persons. It was planned to have more biologists or other experts to test the 3D visualisation, but this was not possible. The results of the questionnaire are therefore highly influenced by their opinion, which does not necessarily have to be the opinion of other experts. The results should therefore not be interpreted as the opinion which all the experts would have about this 3D visualisation. However, although the questionnaire was filled out by only two experts, these experts are involved in the vegetation mapping used as an input in this case study. They therefore do have a lot of expert knowledge about the real situation in the research area about the plants and the distribution and are therefore able to judge the 3D visualisation with their expert knowledge. The questionnaire could therefore also be seen as a kind of a structured interview, which is a good method for colleting expert knowledge (Baarda, 2005, p235).

There was during the test and afterwards also a so called group discussion. Such group discussions are very suitable for subjects without any personal interest of the participants, because they stimulate the generation of new ideas. The participants can react to the ideas and comments of each other and this can result in ideas which the participants would not have thought of (Baarda, 2005, p238). The ideas and comments of the participants where written down in this case and send to the participants for their confirmation on the results.

It was assumed in the expert test that the 3D mouse would result in a better usability than it would with the regular mouse. Most of the expert test was therefore done with the 3D mouse. The 3D mouse however was less usable in the opinion of the experts compared to the regular mouse. Having used this less usable 3D mouse might therefore have resulted in non optimal results. This lower usability could for example have made it more difficult to find the different vegetation areas, which in turn made it more difficult to discover the differences.

9 Conclusion

The following paragraphs will each discuss the conclusions of this research on the vegetation modelling, distribution models, 3D modelling techniques, the combination of this model and on the suitability for nature management support. The various limitations and possibilities of each modelling technique and of the combination of modelling techniques will be discussed. These paragraphs will be brought together in a general conclusion and it will end with recommendations for further research.

9.1 Vegetation modelling

There are two types of vegetation modelling: vegetation mapping and vegetation succession modelling. The vegetation mapping modelling is a process that results in one or more maps with the distribution of vegetation types over an area. The methods available to make these vegetation maps are geostatistical interpolation, generalized linear regression, artificial neural networks and classification trees. The resulting maps can help in interpreting vegetation change when the mapping process is done for multiple years or to test the sensitivity of a vegetation distribution to external change, such as climate change. These maps can be used to communicate with for instance nature managers or lay people. But because traditional maps are more abstract and more difficult to understand to lay people compared to 3D visualisation, it would be better to communicate the vegetation types in an area or the vegetation changes in an area using 3D visualisation. Furthermore, it is possible to communicate the loss of rare plant species, vegetation stress and vegetation risks with a 3D visualisation of vegetation. This is not possible with a vegetation map, because these changes are too subtle. The 3D visualisation can therefore adhere to the original goal of the vegetation map by visualising the vegetation, but the goals for 3D visualisation of a vegetation map can also be extended.

The vegetation succession modelling is developed to model the change from one vegetation type to another vegetation type. This change is caused by changing growth conditions for the plants, such as the soil condition. The outcome of this model is the amount of biomass for five layers in the vegetation. 3D visualisation is a very good means for communicating vegetation succession. It can communicate the effect of nature management on the vegetation succession to nature managers and support them in their task. To visualise a succession model properly, the changes in vegetation should be visible in the 3D visualisation using a time lapse function and the plant species should have a 3D growth function to model the biomass and the time lapse properly.

From the case study, it became clear that vegetation map should come together with more information or another model to describe the composition of the vegetation types. This information is necessary to make the distribution of the plant. If there is a model present which is able to predict the future composition of a vegetation type, it is possible to make 3D visualisations for predicted vegetation maps. This can also be done if the composition of a vegetation type has been described in such a way that it reflects the real vegetation composition without the yearly fluctuations in species abundance in terms of grain, structure and colour. If only the species abundance is available on a year by year basis, it is not possible to make a distribution for a predicted vegetation map because the yearly fluctuations in species abundance are within this data.

9.2 Plant distribution models

The plant distribution models have large differences in their complexity. The more advanced modelling techniques are Agent Based Modelling and Cellular Automata. Agent Based Modelling models the interactions between the agents, which are in this case the individual plants and between the agents and the abiotic circumstances. These interactions are based upon biological algorithms which manage reproduction, dispersion, germination, tolerance levels to abiotic circumstances and competition for resources. The locations of the agents or plants will be determined by these algorithms and this model will therefore result in a distribution of the plant species which are present in a vegetation type. Each plant will need calibrated and validated rules for these algorithms. It is however very time consuming to create, calibrate and validate an Agent Based Model for each vegetation type in the vegetation map.

Cellular Automata are very similar to Agent Based Models, because the same biological algorithms can be used in the model. The difference however is that it is calculated on a raster map and it will be difficult to model differing plant sizes with a fixed cell size. A Cellular Automata Model also requires calibration and validation and is therefore also very time consuming to use.

A simpler model to create a plant distribution is to use a self thinning distribution. The plants are grown in this distribution and will interfere with neighbouring plants when they grow. If a plant does not get the necessary resources, it will die or it will die when it has reached its maximum age. This model therefore requires input information about the size, growth rate and age of the plants. It has so far only been applied to model monocultures and it is unknown whether this model is applicable to a plant distribution for vegetations.

This self thinning distribution model can be used together with an extension of the plant growth model L-systems. The L-systems methodology describes the growth of plants with a rewriting system and can also simulate vegetation growth with multisets. Production rules guide the development of the plants and the spatial component here is provided by the self thinning model.

The simplest model is to let the computer generate a distribution based upon cover percentages or the number of plants per square meter of all plant species for each vegetation type. The computer can create a distribution of all plants over the vegetation type area. The case study however showed that this method is very coarse and may lead to unwanted effects in the distribution, such as unrealistic patterns. The major advantage of this distribution method is the speed and the low amount of biological knowledge necessary to create the distribution. Although the calculation time for one distribution may well exceed an hour, it is very low compared to the research necessary for an Agent Based Model or Cellular Automata.

9.3 3D plant models and growth models

There are two approaches to 3D plant modelling: the accurate approach and the sketch based approach. The accurate approach can be taken via the L-systems modelling technique and the AMAP modelling technique. These two modelling techniques make it possible to model the plants and their growth in 3D based upon knowledge about the growth and development of all plant organs. These modelling techniques are therefore obligatory when for instance a vegetation succession model with biomass information has to be 3D visualised. When properly modelled, the 3D plant models will show grow behaviour which they also tend to do in reality and can in this way for instance visualise poor abiotic circumstances for a plant. An accurate 3D model of a plant using L-systems of AMAP also requires a good study of the growth and shape of the plants in reality. The major advantage is that these accurate models are suitable for a conversion from cover percentage to the number of plants per square meter based upon the cover percentage of a single 3D plant model of a square meter and is therefore a solution for the cover percentage problem which occurred in the case study.

The sketch based approach can be done via the Xfrog software or via L-systems. It only requires some photographs from different angles of the plant to model the plant in 3D. Especially Xfrog is very suitable for quickly creating a 3D model of a plant. L-systems is less quick to use, because the L-systems code still has to be very well written to model all the plant correctly with the production rules. The expert test showed that these models can be recognizable although they are not modelled accurate. When they as experts can recognize the plant species, it can be concluded that the sketch based 3D models of the plants are suitable for the purpose of 3D visualisation.

It would however be advisable to use some more information when 3D modelling the plants to model plant height differences for each plant species. The expert test showed that some of the plant species differ more in relative height than other plant species and that the height difference of 25%, which was used in the case study, was too coarse with respect to these differences. Information on the size differences of the plant species can make it possible to export the plant models with different sizes for the same model. Furthermore, a 3D visualisation of vegetation would look more realistic if a plant species had more 3D models with varying shapes and sizes, because the plant shape and size does also vary in reality.

9.4 Combining the models

The key to combining the models into a 3D visualisation is the available vegetation type description. In this case study, this was a database containing for each location and each year the amount of species as a cover percentage. This makes this database unsuitable, because the required input information is the number of plants per square meter. Furthermore, this vegetation description did not have a description of the vegetation which is valid for all years, like some kind of mean vegetation. It was therefore impossible to make 3D vegetation visualisations for future vegetation development scenarios. It is not possible to make a conversion from cover percentage to plants per square meter as long as the 3D plant models are not accurate modelled. It is therefore necessary that the descriptions of the vegetation contain the number of plants per square meter if these vegetation maps are to be used for 3D vegetation visualisation. If a vegetation map together with descriptive information does not contain the number of plants per square meter, it is technically impossible to properly 3D visualise this vegetation map. It is therefore also technically not possible to 3D visualise a predicted future vegetation map when there is no information about the future abundance of individual plant species available.

Furthermore, care has to be taken when vegetation maps are used as input for 3D visualisation of vegetation. It is necessary to check for gaps in the input map and, when these are found, to check whether this gap can be clearly 3D visualised as a gap. Furthermore, the use of sharp boundaries in the vegetation map may lead to sharp boundaries between the 3D vegetation types and this is not necessarily the case in reality. Generalisation in the map can lead to plants being distributed at locations at which these plants normally don't grow.

An example of these sharp boundaries and map generalisation is shown in the map in Figure 42 and the screenshot of the 3D visualisation in figure 43. This map shows the vegetation areas on top of the aerial photograph of Ameland. The vegetation areas are calculated using kriging for the whole research area. Because the research area is extended to the north in the middle of the map, the extension has become mostly vegetation type D. A closer look at the aerial photograph reveals that this extension reaches the beach, which is the white area in the aerial photograph. The effect of this extension is visible in Figure 43: the Hippophae rhamonides grows on the beach, which it does not in reality. The problem here is that the distribution depends on the vegetation maps and a minor flaw in the vegetation map, such as this extension being a little bit too far to the north, results in these plants growing at the beach. However, it was assumed that the input vegetation map was correct, but the 3D visualisation together with the expert opinion clearly showed that this was not the case.

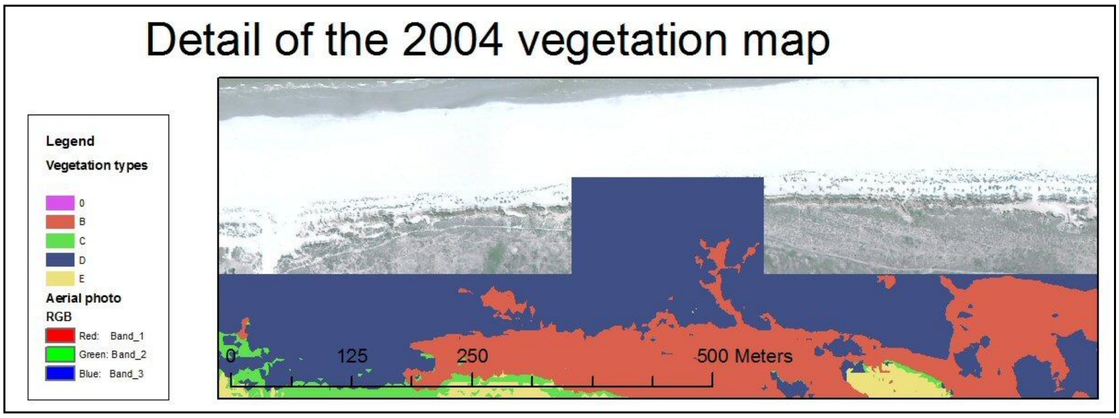


Figure 42: detailed map showing the vegetation areas on top of the aerial photograph

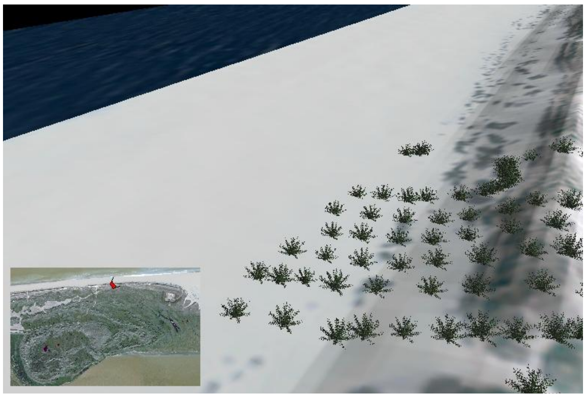


Figure 43: Hippophae rhamonides growing at the beach in the 3D visualisation

This could be solved by introducing more information into the distributing process and it should theoretically well be possible to introduce a rule to avoid these plants at the beach. The suitable models to do this are Agent Based Modelling and Cellular Automata, which have the possibility to model the interactions between plants and the interactions between the plants and the abiotic circumstances. Via the process of calibrating and validating, it should be possible to restrict the growth of this specific specie on the beach. The vegetation map also results in very sharp boundaries between the vegetation types in the 3D visualisation. This problem was already expected in the literature study as an effect of using vegetation maps with sharp boundaries. Although these sharp boundaries can also be found in reality, it is certainly not standard. Therefore more fuzzy boundaries should be generated for the species which don't have sharp boundaries in reality. A possible solution for these sharp boundaries could also be to bypass the vegetation maps and to generate the plant distribution on the species response to the abiotic circumstances. Input datasets with these abiotic circumstances should not be classified or generalised much, because this may lead to sharp boundaries as well.

However, if information about the plants is available as the number of plants per square meter, it is technically possible to 3D visualise a vegetation. The software package, Virtual Terrain Project, which was used for this case study is capable of importing the 3D plant models, of making the distribution of the plant species for each vegetation type and of importing a DEM and an aerial photograph. To do so, VTP consist of three programs with each a specific task: CManager, VTBuilder and Enviro. The CManager is a program that manages the 3D models and which has to be used to create the global content file. The VTBuilder program is used to prepare the GIS data which is to be used in the 3D visualisation. The DEM has to be converted in this program to a special file format which Enviro can import. Before a DEM is loaded into VTBuilder, it might need some pre-processing in a generic GIS package. The vegetation distribution also can also be made in this software package. In order to make a vegetation distribution for multiple vegetation types, a shapefile with the vegetation types will need some pre-processing to translate the vegetation types into integers. Together with a special xml file with information about the 3D models of the plants and a so called bioregions file with the number of plants per square meter for each vegetation type, it is possible to generate a plant distribution. This plant distribution created in VTBuilder will however show some patterns which are unnatural. The third program, Enviro, is used to run the 3D visualisation. The global content file of CManager, plant distribution file, DEM and the aerial photograph are loaded into it and when this is done, the user is able to move around in the 3D vegetation visualisation. The aerial photograph can be loaded directly into Enviro as long as its size fits within the capacity set by the graphical processing unit of the computer.

The last technical limitation can be the hardware of the computer which is used to run the 3D visualisation on. The complexity of the larger plants together with the amount of plants and the visibility distance of these plants require a very fast and recent graphical processing unit to render the images quick enough to give an acceptable frame rate. When the graphical processing unit is too slow, the options are to lower the complexity of the 3D model or to lower the visibility distance of the plants. The first solution might make the plants no longer recognizable and the second solution can make the vegetation analysis impossible. The expert test showed clearly that the visibility distance of the plants should be several hundreds of meters at least to make their vegetation analysis methodology possible.

On these results from the case study, it can be concluded that it is technically possible to make a 3D visualisation of vegetation maps with the used software for this case study if these vegetation maps with their descriptive information contain the number of plants per square meter.

9.5 Nature management support

The 3D visualisation as it was realised in the case study does not support the nature management process. There are several reasons for this. The first reason is that it was not possible in the case study to make 3D visualisations for future vegetation developments because the necessary information about the species abundance for this vegetation development is missing. A dynamic vegetation model must model the species abundance over the years in order to be suitable for 3D vegetation visualisation. The second reason why it is not possible to use the 3D visualisation from the case study is that the vegetation types were not recognizable by the experts. And if the vegetation types cannot be recognized, then also the changes in vegetation cannot be recognized and it is therefore not suitable to support nature management decisions. The 3D visualisation can however be improved in order to let the vegetation types be distinguishable. To do so, more plants have to be 3D modelled and visualised and also the plants which contribute to the grain, structure and colour of a vegetation type should be 3D visualised. This requires research into the plant species which contribute to these aspects and the plants which contribute should be selected to be 3D visualised. Furthermore, it might be necessary to model the dead plant material on the ground if this covers a large part of the ground. This dead plant material however is not necessarily part of the vegetation model and can in such cases only be added based on expert knowledge.

9.6 *General conclusion*

The possibilities for 3D vegetation visualisation are graphically represented in the figures 44 and 45. The blue boxes in these figures represent the vegetation mapping models, the purple boxes the distribution models, the green boxes the 3D plant models and the orange boxes the 3D visualisation outcome. Figure 44 shows the modelling possibilities for vegetation succession models. Only the accurate 3D models can be used for the vegetation succession modelling, because the biomass of the plants should be properly 3D visualised. Although it should technically be possible to use AMAP 3D models for the 3D plant models in combination with an L-systems distribution, it would not make much sense, because the L-systems distribution model will also be able to control the L-systems 3D models.

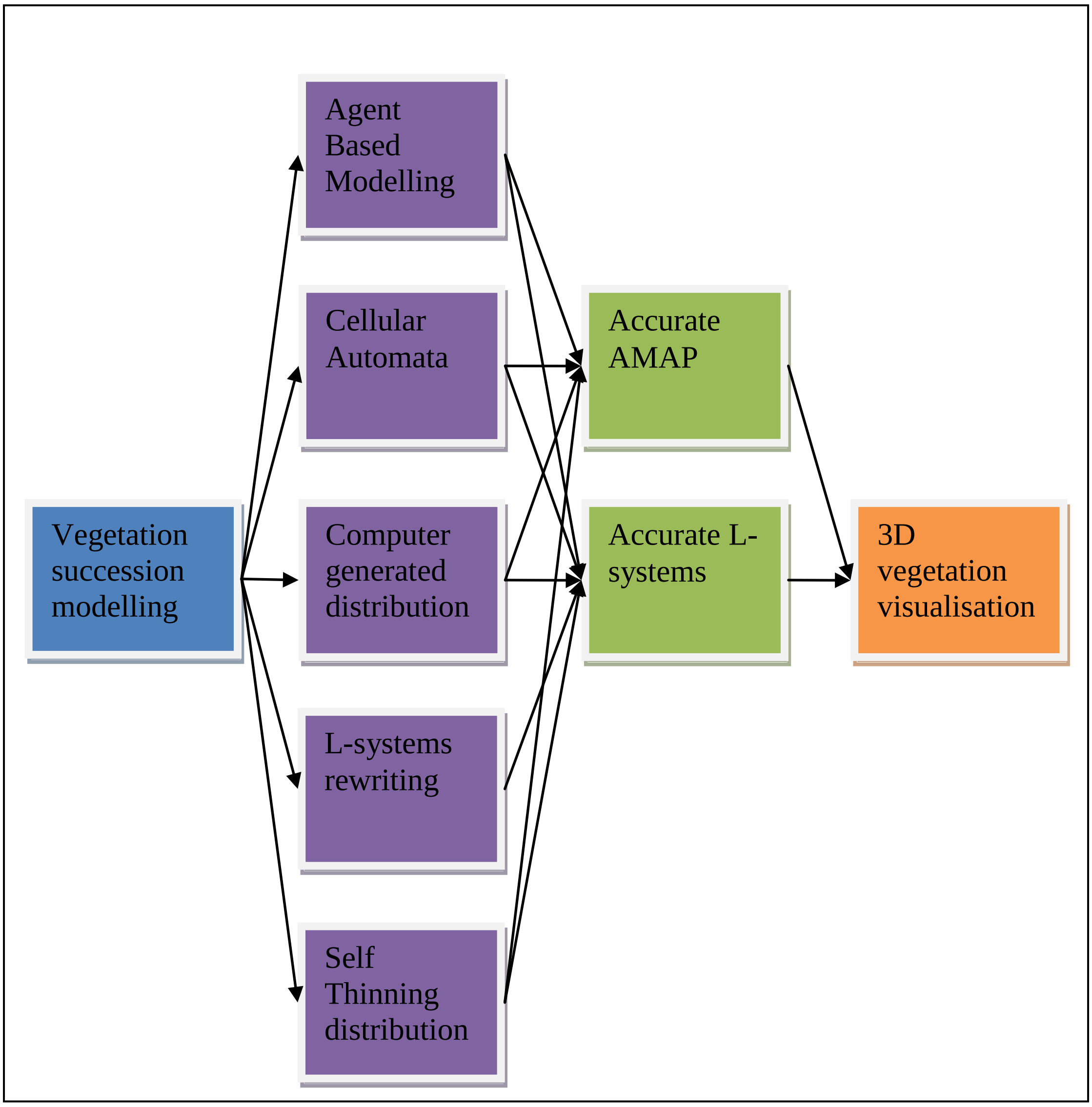


Figure 44: Modelling possibilities for 3D visualisation of succession models

Figure 45 shows the modelling possibilities of vegetation mapping models. It is possible to use the sketch based 3D plant models for these visualisations, because there is no biomass in the input model which should be 3D visualised. The L-systems distribution is again only connected to the L-systems 3D models, because it allows for a good integration of these modelling techniques.

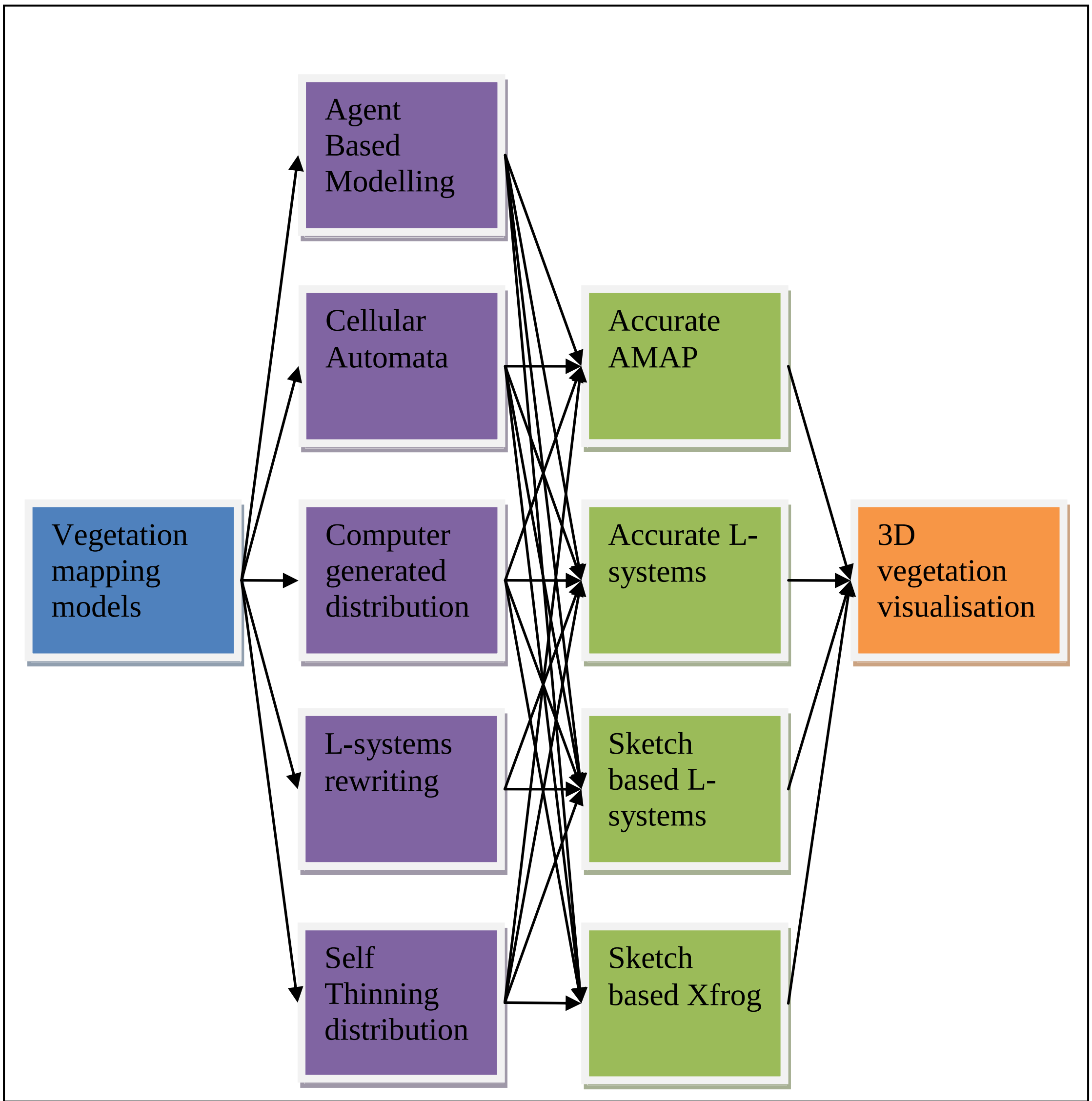


Figure 45: Modelling possibilities for 3D visualisation of vegetation maps

Although the 3D visualisation of vegetation failed in the case study, it should be possible to make a 3D vegetation visualisation of dynamic vegetation models. To do so, it will require good predictions of plant species abundance for future situations and the number of plants per square meter for each vegetation type. Furthermore, it is necessary to select the plants which contribute to the grain, structure and colour of a vegetation type for 3D modelling of the plant. A computer generated distribution and Xfrog sketch based 3D plant models are the quickest models to use for a 3D vegetation visualisation of dynamic vegetation models.

9.7 Further research

The plant cover percentages will need to be converted to the number of plants per square meter. Biologists use the Braun-Blanquet scale or derivatives of this scale to study the plant abundance and cover (Wikum & Shanholtzer, 1978) and it is therefore not to be expected that they will change this and record the number of plants per square meter. It will therefore always be necessary to convert this cover percentage from the Braun-Blanquet scale to the number of plants per square meter. Possible solutions are accurate 3D models of the plant species which can be used to calculate the cover percentage of one plant of a square meter. Another solution would be to count the number of plants per square meter in the field and to store this together with the cover percentage in the datasets. This does however not solve the problem of the not identifiable individuals, such as grass. Accurate modelling of the plants species will however require a lot of extra time and research and storing the number of plants per square metre would require an adaptation in the research methodology of the biologists and are therefore both not very feasible. It is therefore necessary to research what the possibilities are to use sketch based 3D plant models for cover percentage conversion and what the requirements for the sketch based 3D plant models quality would be to do so.

Another problem which occurred in the 3D visualisation was the sharp boundaries between the vegetation types. These sharp boundaries are not always natural and for the cases it is not natural, it should be avoided to generate a more natural boundary in the 3D visualisation. Under the assumption that the vegetation maps are created by biologists who will continue to generate vegetation maps with sharp boundaries, this further research has to focus on the possibilities to convert a sharp boundary of a vegetation map into a fuzzy boundary. This should go together with research into how these fuzzy vegetation maps can be used as input for the plant distribution model. The vegetation distribution model which was used during this research required sharp boundaries in the input shape files and is therefore not capable of interpreting a fuzzy boundary map correctly.

The expert test in this research was only done with two biologists from WUR. Furthermore, the 3D visualisation in the case study had insufficient quality to function as an information system for nature management. However, if the quality of the 3D visualisation improves, the 3D visualisation should be presented to and tested with nature managers. To do so, scenarios will have to be created of different management options and these must be shown to the nature managers and they should be questioned about their needs and wishes in order to research whether 3D visualisation of dynamic vegetation models would support them in the nature management.

From the discussion with the experts, it became clear that there is a large database with plant species responses to abiotic circumstances. It might be possible to bypass the vegetation model and to make the distribution of the plants using information on their response to the abiotic circumstances. The input maps for such a distribution could be ground water level maps, soil type maps, maps on soil acidity and digital elevation maps. Unknown however is whether the response information is available for the plants growing in the research area, whether the input maps are precise enough and how the species response should be converted to the number of plants per square meter. It would however be a good solution to avoid plants being distributed at locations where they in reality don’t grow, such as Hippophae Rhamonides growing at the beach. More research into this possible option is therefore needed.

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Appendix A: Turtle commands of L-systems

Name	Alias	Interpretation
[	SB	Push the state in the stack.
]	EB	Pop last state from turtle stack and make it the its current state.
F		Move forward and draw. Params: length , topradius.
f		Move forward and without draw. Params: length.
X	MouseIns	Module inserted just before module selected by user in visualisation.
%	Cut	Cut the remainder of the current branch in the string.
*		Used to specify Null production (produce *) or matching of any module in rules predecessor.
?P	GetPos	Request position vector information. Params : x,y,z or v (optional, default=Vector3, filled by Turtle).
?H	GetHead	Request heading vector information. Params : x,y,z or v (optional, default=Vector3, filled by Turtle).
?U	GetUp	Request up vector information. Params : x,y,z or v (optional, default=Vector3, filled by Turtle).
?L	GetLeft	Request left vector information. Params : x,y,z or v (optional, default=Vector3, filled by Turtle).
?R	GetRight	Request right vector information. Params : x,y,z or v (optional, default=Vector3, filled by Turtle).
@Gc	StartGC	Start a new generalized cylinder.
@Ge	EndGC	Pop generalized cylinder from the stack and render it.
{	BP	Start a new polygon.
}	EP	Pop a polygon from the stack and render it.
@M	MoveTo	Set the turtle position. Params : x, y, z (optionals, default = 0).
@R	SetHead	Set the turtle Heading and Up vector. Params: hx, hy, hz, ux, uy, uz (optionals, default=0,0,1, 1,0,0).
+	Left	Turn left around Up vector. Params : angle (optional, in degrees).
-	Right	Turn right around Up vector. Params : angle (optional, in degrees).
^	Up	Pitch up around Left vector. Params : angle (optional, in degrees).
&	Down	Pitch down around Left vector. Params : angle (optional, in degrees).
/	RollL	Roll left around Heading vector. Params : angle (optional, in degrees).
\	RollR	Roll right around Heading vector. Params : angle (optional, in degrees).
|	TurnAround	Turn around 180deg the Up vector.

@v	RollToVert	Roll to Vertical : Roll the turtle around the H axis so that H and U lie in a common vertical plane with U closest to up
@O	Sphere	Draw a sphere. Params : radius (optional, should be positive, default = line width).
@o	Circle	Draw a circle. Params : radius (optional, should be positive, default = line width).
@L	Label	Draw a text label.
_	IncWidth	Increase the current line width or set it if a parameter is given. Params : line width (optional).
!	DecWidth	Decrease the current line width or set it if a parameter is given. Params : line width (optional).
SetWidth		Set current line width. Params : line width.
;	IncColor	Increase the current material index or set it if a parameter is given. Params : color index (optional, positive int).
,	DecColor	Decrease the current material index or set it if a parameter is given. Params : color index (optional, positive int).
SetColor		Set the current material index. Params : color index (positive int).
@Dd	DivScale	Divides the current turtle scale by a scale factor, Params : scale factor (optional, default = 1.0).
@Di	MultScale	Multiplies the current turtle scale by a scale factor, Params : scale factor (optional, default = 1.0).
@D	SetScale	Set the current turtle scale, Params : scale (optional, default = 1.0).
surface		Draw the predefined surface at the turtle's current location and orientation. Params : surface name (by default, 'l' exists), scale factor (optional, default= 1.0, should be positive).
~		Draw the predefined surface at the turtle's current location and orientation. Params : surface name (by default, 'l' exists), scale factor (optional, default= 1.0, should be positive).
@g	PglShape	Draw a geometry at the turtle's current location and orientation. Params : a geometric model, a scale factor (optional, should be positive).

Appendix B: Cover percentages table

	2001 mean		2001 n	2001 stdev	**2004 mean**		2004 n	2004 stdev	**2006 mean**		2006 n	2006 stdev	**2008 mean**		2008 n	2008 stdev
Vegetation type 0																
No plants	0,000	0,000	0	0,000	0,000	0,000	0	0,000	0,000	0,000	0	0,000	0,000	0,000	0	0,000
Vegetation type B										0,000				0,000		
Potentilla Anserina	19,793	0,198	14	22,111	18,586	0,186	29	22,658	9,414	0,094	29	13,802	16,031	0,160	35	25,059
Juncus maritimus	0,000	0,000	14	0,000	1,207	0,012	29	6,386	1,207	0,012	29	6,386	0,060	0,001	35	0,333
Hippophae rhamonides	6,786	0,068	14	20,668	6,817	0,068	29	20,804	4,572	0,046	29	13,706	2,274	0,023	35	10,215
Scirpus Maximus	0,164	0,002	14	0,515	2,048	0,020	29	6,902	0,638	0,006	29	1,803	1,154	0,012	35	5,823
Triglochin maritima	0,000	0,000	14	0,000	0,003	0,000	29	0,018	0,000	0,000	29	0,000	0,000	0,000	35	0,000
Vegetation type C																
Potentilla Anserina	0,000	0,000	16	0,000	1,435	0,014	37	6,103	0,724	0,007	37	2,665	4,919	0,049	32	17,463
Juncus maritimus	0,000	0,000	16	0,000	0,000	0,000	37	0,000	0,000	0,000	37	0,000	0,000	0,000	32	0,000
Hippophae rhamonides	5,575	0,056	16	9,539	13,276	0,133	37	24,312	11,500	0,115	37	20,874	6,856	0,069	32	15,948
Scirpus Maximus	0,000	0,000	16	0,000	1,135	0,011	37	5,757	1,351	0,014	37	6,113	0,472	0,005	32	2,609
Triglochin maritima	0,000	0,000	16	0,000		0,000	37	0,000	0,000	0,000	37	0,000	0,000	0,000	32	0,000
Vegetation type D																
Potentilla Anserina	0,000	0,000	16	0,000	0,003	0,000	31	0,018	0,003	0,000	31	0,018	0,774	0,008	31	2,893
Juncus maritimus	0,000	0,000	16	0,000	0,000	0,000	31	0,000	0,000	0,000	31	0,000	0,000	0,000	31	0,000
Hippophae rhamonides	3,513	0,035	16	8,890	5,861	0,059	31	13,527	6,665	0,067	31	14,374	10,794	0,108	31	21,445
Scirpus Maximus	0,000	0,000	16	0,000	0,000	0,000	31	0,000	0,000	0,000	31	0,000	0,000	0,000	31	0,000
Triglochin maritima	0,000	0,000	16	0,000	0,000	0,000	31	0,000	0,000	0,000	31	0,000	0,000	0,000	31	0,000
Vegetation type E																
Potentilla Anserina	0,000	0,000	23	0,000	0,000	0,000	43	0,000	0,000	0,000	43	0,000	0,063	0,001	41	0,313
Juncus maritimus	0,000	0,000	23	0,000	0,000	0,000	43	0,000	0,000	0,000	43	0,000	0,007	0,000	41	0,046
Hippophae rhamonides	4,883	0,049	23	11,751	6,453	0,065	43	14,979	6,067	0,061	43	14,963	6,546	0,065	41	13,587
Scirpus Maximus	0,000	0,000	23	0,000	0,000	0,000	43	0,000	0,000	0,000	43	0,000	0,002	0,000	41	0,015
Triglochin maritima	0,000	0,000	23	0,000	0,000	0,000	43	0,000	0,000	0,000	43	0,000	0,000	0,000	41	0,000

Appendix C: Questions of the expert test

Expectations before the test starts		Answer type
	Before using the 3D visualisation What do you expect from this 3D visualisation?	Textbox
Interesting/engaging		
1	*This question will be repeated for each of the four visualisations.* Move to the vegetation and view it from above. Inspect the whole area. Try to discover the different vegetation areas. It is interesting to move around in the 3D visualisation.	Likert
2	*This question will be repeated for each of the four visualisations.* Zoom in to the plants. It is interesting to see the plants in detail.	Likert
3	*This question will be repeated for each of the four visualisations.* Try to discover the different vegetation areas. It is interesting to discover the different vegetation areas.	Likert
4	*On loading the 2004 3D visualisation* I'm curious to explore the 2004 3D visualisation.	Likert
5	*On loading the 2006 visualisation* I'm curious to explore the 2006 3D visualisation.	Likert
6	*On loading the 2008 visualisation* I'm curious to explore the 2008 3D visualisation.	Likert
Comprehensible/visually clear		
1	*After the 2008 visualisation.* I prefer the 3D visualisation above the vegetation map.	Likert
2	*After the 2008 visualisation.* The 2D vegetation map gives a better overview of the distribution of the different vegetation areas compared to the 3D visualisation	Likert
3	*After the 2008 visualisation.* The 2D vegetation map gives a better overview of the distribution and abundance of the plant species	Likert
4	*After the 2008 visualisation.* The 2D vegetation map gives a better overview of the vegetation changes over the years compared to the 3D visualisation	Likert
Accurate		
1	*After all the visualisations.* The distribution of the plants over the research area or the vegetation areas is comparable to the real situation in the Ameland research area.	Likert

2	*After all the visualisations.* What is not realistic? How should this be improved?	Textbox
Realism		
1	Move around the whole research area. *After exploring the 2001 3D visualisation.* The four types of vegetation have distinctive characteristics.	Likert
2	Move around the whole research area. *After exploring the 2004 3D visualisation.* The four types of vegetation have distinctive characteristics.	Likert
3	Move around the whole research area. *After exploring the 2006 3D visualisation.* The four types of vegetation have distinctive characteristics.	Likert
4	Move around the whole research area. *After exploring the 2008 3D visualisation.* The four types of vegetation have distinctive characteristics.	Likert
5	*Question to follow after questions 1-4* If you cannot make a distinction or if it is hard to make a distinction, what should in your opinion be improved?	Textbox
6	*When exploring the 2004 3D visualisation, which contains all the plants.* Zoom in to the plants. The plant species in the 3D visualisation are recognizable.	Likert
7	If you cannot recognize all the plants, which one don't you recognize? Give a description of the shape and colour.	Textbox
8	Estimate the size of the plants. The 3D plant models have a realistic size.	Likert
9	Which ones are too large or too small?	Textbox
10	The 3D plant models have realistic shapes.	Likert
11	Which plants do have unrealistic shapes?	Textbox
12	The 3D plant models have realistic colours.	Likert
13	Which plants are unnatural coloured? Box	Textbox
14	*When exploring the 2006 visualisation* Navigate to the area as shown in the figure. It is realistic to find these plants growing on the beach.	Likert
15	It is realistic to find these plants growing on the north side of the dune near the beach.	Likert
16	The cloudy sky background improves the feeling of realism of the 3D visualisation.	Likert
17	This sky distracts me from the vegetation analysis task.	Likert
18	*When exploring the 2004 visualisation*	Likert

	The white border in the 2004 visualisation viewed from a large distance degrades the realism of the visualisation.	
19	The white border in the 2004 visualisation viewed from a close by (zoom in until you can clearly see the plant details) degrades the realism of the visualisation.	Likert
"Evaluatable" and "Legitimate"		
1	*After all the visualisations.* I understand how the 3D visualisation was created from the vegetation maps.	Likert
2	*After all the visualisations.* Do you have comments on the process of creating a 3D visualisation out of the vegetation maps? Are there things wrong?	Textbox
Usability		
1	*After all the visualisations. For the 3D mouse navigation and for the regular mouse with the 'panoramic flyer' setting.* It is easy to navigate in the 3D environment.	Likert
2	*After all the visualisations. For the 3D mouse navigation and for the regular mouse with the 'panoramic flyer' setting.* I was able to reach all the positions and locations I wanted to reach.	Likert
3	*After all the visualisations. For the 3D mouse navigation and for the regular mouse with the 'panoramic flyer' setting.* It is easy to move up and down.	Likert
4	*After all the visualisations. For the 3D mouse navigation and for the regular mouse with the 'panoramic flyer' setting.* It is easy to move left and right.	Likert
5	*After all the visualisations. For the 3D mouse navigation and for the regular mouse with the 'panoramic flyer' setting.* It is easy to move forward and backward.	Likert
6	*After all the visualisations. For the 3D mouse navigation and for the regular mouse with the 'panoramic flyer' setting.* It is easy to tilt forward and backward.	Likert
7	*After all the visualisations. For the 3D mouse navigation and for the regular mouse with the 'panoramic flyer' setting.* I could get close enough to the plants to view all their details.	Likert
8	*After all the visualisations.* The overview map on the bottom right was helpful.	Likert
9	*After all the visualisations.*	Likert

	The north arrow was helpful.	
10	*After all the visualisations.* The white border in 2004 was helpful in the navigating process.	Likert
11	*After all the visualisations.* The 3D mouse was intuitive to work with.	Likert
12	*After all the visualisations.* It was easy to master the capabilities of the 3D mouse in the 3D visualisation.	Likert
13	*After all the visualisations.* The panoramic flyer was intuitive to work with.	Likert
14	*After all the visualisations.* It was easy to master the capabilities of the panoramic flyer.	Likert
15	*After all the visualisations.* Which navigation is better: 3D mouse or panoramic flyer?	Choice
16	*After all the visualisations.* Would a 3D visualisation be helpful in your research? Yes / no. For what purpose?	Choice Textbox
17	*After all the visualisations.* What other possible uses could there be for 3D vegetation visualisation?	Textbox
18	I want to see more or other information than the aerial photograph, such as information on ground water levels, chances on sea water intrusion, number of days the area is flooded etc.	Likert
19	What other possible uses could there be for 3D vegetation visualisation?	Textbox
Overall opinion		
1	*After all the visualisations.* The 3D visualisation of vegetation matched my expectations. What differences were there?	Likert Textbox
2	*After all the visualisations.* This is a successful visualisation of the vegetation in the research area.	Likert
3	*After all the visualisations.* What is your overall opinion on this 3D visualisation of vegetation?	Textbox

Appendix D: Expert test report and questionnaires

Expert test report

Report of the expert test of the 3D visualisation of vegetation January 21 2010

Contents

Visibility distance

When Han or Rik enters the field for research, the first thing they do is to look at the vegetation structure, grain size and colours. This gives them a good idea of which vegetation type is where and also an idea of which parts of the whole area will be interesting to investigate further. In fact they create a vegetation map in their mind when they overview the whole area. The structure, grain size and colour are determined by the generic and abundant plant species and not by the rare species. The rare species are only discovered when they look to the plants down by their feet if they investigate a vegetation type in more detail. The current 3D visualisation does not suit their method of analysis, because the structure of the vegetation becomes not very clear and because there are not enough differences in colour. This is the reason why the different vegetation types do not have specific characteristics in their opinion. It is also necessary to set the visibility distance of the plants at 300 meters, because it makes it possible to look at the vegetation in order to see the structure, grain size and colour of the vegetation. The performance drop in the software is less important than the visibility distance. As they point out, they will get accustomed to the low frame rates as they are accustomed to other slow working software, like a text processor with large documents. However, if they want to use it as a communication mean, they will need performance as well.

Plant distributions and patterns

The Hippophae is too dominant; there should be more grassy vegetation with more grasses and thistles. Furthermore, many plants tend to cluster and this is not taken care of in the current 3D visualisation. The patterns which can be seen in the 3D visualisation can also be found in nature, due to nature management measures or plant specific distribution characteristics, but are certainly not standard for all plants. The patterns in the visualisation are therefore not representing a natural distribution. Furthermore, there is not taken care of the borders between the different vegetation areas. These borders can be fuzzy, but this does not necessarily have to be. However, in this 3D visualisation all the borders are clearly visible. The reasons for this are the boundaries of the vegetation map, which make a sharp division between the one and the other vegetation type. More research into fuzzy boundaries in relation to vegetation areas is necessary for proper modelling of vegetation boundaries.

Plant size and shape

The plants have different variations in size: the Hippophae varies from very small plants of about 10 centimeters to large plants of more than 1 metre. The Potentilla Anserina on the other side does hardly vary in size. This is insufficient modelled by VTBuilder, because it can only model the height differences for all the plants together. The height of all the plants varies from 75% to 100% of the original 3D model height of the plant, but for Hippophae (1 metre standard size in the 3D model), this should be more like from 10% to 150% and for Potentilla Anserina about 90% - 100%. It can be solved by importing more models with different sizes for the same plant species. The realism of the plants can be improved by adding more variation in the plant models. There are many shapes and sizes found in nature and it would be better if this was also done in the 3D visualisation.

Which plants should be visualised?

The choice of plants to be visualised depended on the available photographs of the plants. It would be better to make a selection for the 3D models based upon the recordings dataset. The species that determine the large overview by their abundance, size, colour or grain should be selected to be 3D modelled and visualised. Unknown is the amount of species which should be 3D modelled per vegetation type to get distinctive vegetation types.

Individual plants, cover and dead material

What is an individual plant? The cover of for instance grass can easily be estimated by a biologist, because he does not have to take into account the individual grass plant. It becomes difficult when grass is to be modelled in 3D, because it is then necessary to know what an individual grass plant is. Furthermore, modelling the abundance of the grass by the number of plants per square meter is impossible if only the cover percentage of an unknown amount of individual grass plants is known. It is possible to use photographs of the ground in the 3D visualisation to improve realism and to avoid the problems with grass individuals, but this can only be done when the grass is decoupled from the vegetation mapping and vegetation data. This subject is also related to the dead plant materials. Dead plant materials can also cover large parts of the ground, but they are in general not included in the datasets of vegetation mapping. The vegetation succession modelling (SMART2SUMO) does include dead plant materials in the model. There are therefore two reasons for modelling dead plant materials: because it is part of the model or because it is likely to improve the realism of the 3D visualisation. It can be modelled the simple way using photographs, but there could be reasons to model dead plant materials more sophisticated.

Another method for modelling the abundance

The vegetation maps can also be bypassed to model the abundance of plant species. There is a large database containing the response of plant species to the abiotic characteristics. If maps containing the abiotic circumstances in an area are overlaid, it should theoretically be possible to calculate the chance of finding the specie at a specified place. How this chance should be translated to the number of plants per square meter or the cover percentage is unclear. However, it will offer the opportunity to model the distribution of species for the future using abiotic changes within scenarios. This solves the problem that existed in this case study. There was a wish to use scenarios in this 3D visualisation too, but uncertainty about the changes in plant abundance within a vegetation type made this impossible. This however largely depends on the availability of response data for the plants growing in the area one wants to model and on the availability of maps with information about the abiotic circumstances

Expert test of the 3D visualisation of vegetation

January 21, 2010

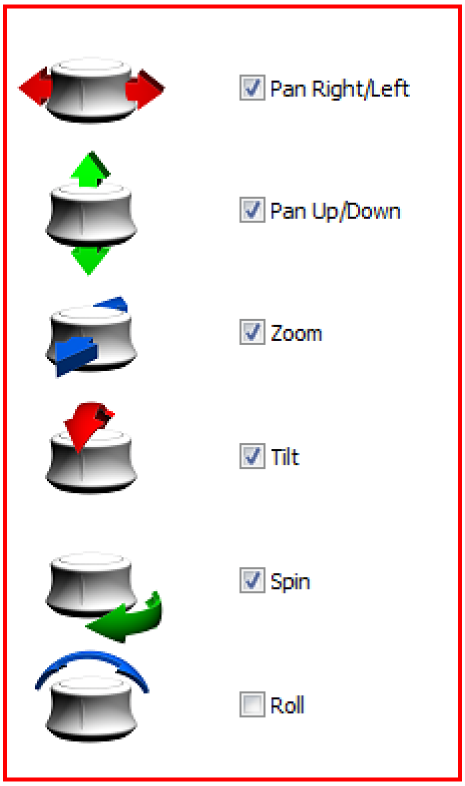
Expectations

1. **What do you expect from this 3D visualisation?**

Realistic image of vegetation where I can walk around. Visualisation of temporal changes like an accelerated movie

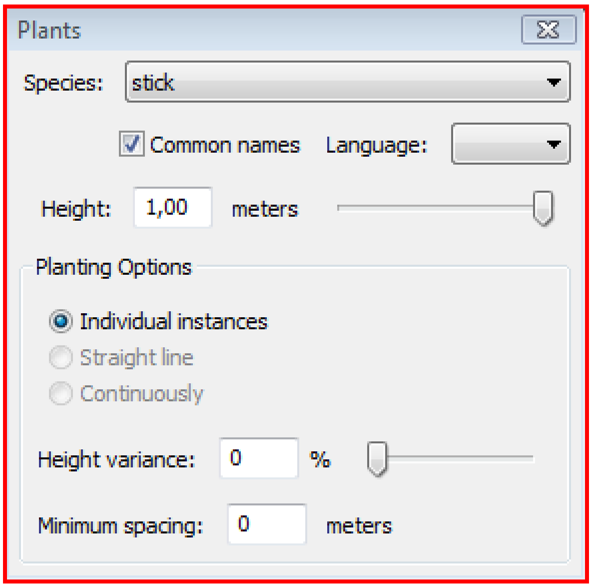
Moving around with the 3D mouse

You are going to use the 3Dconnexion Spacenavigator to move around in the 3D visualization. The figure on the left shows the possibilities with this mouse



- Pan right/left: you will move to the right or the left
- Pan up/down: you will move upward or downward
- Zoom: you will move forward or backward
- Tilt: your viewing and moving direction will go up or down
- Spin: Turn around your axis
- Roll: Disabled

How to measure a plant



- Click the green tree on the menu bar on top
- You can now plant every plant everywhere you want, which is the main goal of this function
- Now select from the drop down list at the top the specie called "Stick"
- Set the height to 1 meter
- Set the height variance to 0%
- Set the minimum spacing to 0 meters
- Move your mouse pointer to the location at which you want to measure a plant, you will see some guiding axes which will help you placing the stick
- When you've found the location, click and a 1 meter high red and white stick will be placed. One red or white part is 10cm.
- Move to a position at which you can compare the plant height with the stick and estimate the height of the plant.

The 2001 visualisation

Time: 10 min

- Move forwards to the vegetation and view it from above. Inspect the whole area.
- Try to discover the different vegetation areas.

2. It is interesting to move around in the 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	Agree	**Strongly Agree**

- Zoom in to the plants.

3. It is interesting to see the plants in detail.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

- Try to discover the different vegetation areas.

4. It is interesting to discover the different vegetation areas				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

5. The four types of vegetation have distinctive characteristics.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

6. If you cannot make a distinction or if it is hard to make a distinction, what should in your opinion be improved?
Vegetation types should be more different even from a distance

The 2004 visualisation

Time: 20 min

- Click “Scene” in the menu bar on top. Then click “Go to terrain”. Select “Ameland 2004”. Click OK
- *The 2004 visualisation will now load. Please answer the next statement while it loads*

7. I’m curious to explore the 2004 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	Agree	**Strongly Agree**

- Move forwards to the vegetation and view it from above. Inspect the whole area.
- Try to discover the different vegetation areas.

8. It is interesting to move around in the 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	Agree	**Strongly Agree**

- Try to find a vegetation type which contains all the six plants
- Zoom in to the plants.

9. It is interesting to see the plants in detail.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

10. The plant species in the 3D visualisation are recognizable.				
Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

11. If you cannot recognize all the plants, which one don’t you recognize?Give a description of the shape and colour
Hippophae was not recognizable Potentilla is ok Triglo is also ok Scirpus mar is also ok Juncusmar is more or less recognizable

12. Estimate the size of the plants. The 3D plant models have a realistic size.

Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

13. Which ones are too large or too small?
Hippophae too small or variation too small Others more or less ok

14. The 3D plant models have realistic shapes.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

15. Which plants do have unrealistic shapes?
Hippophae For others shape is quite ok, but lower part (leaves or herbs) are often missing

16. The 3D plant models have realistic colours.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

17. Which plants are unnatural coloured?
Hippophae -> too green, is grey in reality Armeria -> Flower is pink Juncus mar -> is Green

- Try to discover the different vegetation areas.

18. It is interesting to discover the different vegetation areas				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

19. The four types of vegetation have distinctive characteristics.				
Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

20. If you cannot make a distinction or if it is hard to make a distinction, what should in your opinion be improved?
The view from a distance should be more realistic

21. The white border in the 2004 visualisation viewed from a large distance degrades the realism of the visualisation.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

22. The white border in the 2004 visualisation viewed from a close by (zoom in until you can clearly see the plant details) degrades the realism of the visualisation.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

The 2006 visualisation

Time: 20 min

- Click “Scene” in the menu bar on top. Then click “Go to terrain”. Select “Ameland 2006”. Click OK
- *The 2006 visualisation will now load. Please answer the next statement while it loads*

23. I’m curious to explore the 2006 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	Agree	**Strongly Agree**

- Move forwards to the vegetation and view it from above. Inspect the whole area.
- Try to discover the different vegetation areas.

24. It is interesting to move around in the 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	Agree	**Strongly Agree**

- Zoom in to the plants.

25. It is interesting to see the plants in detail.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

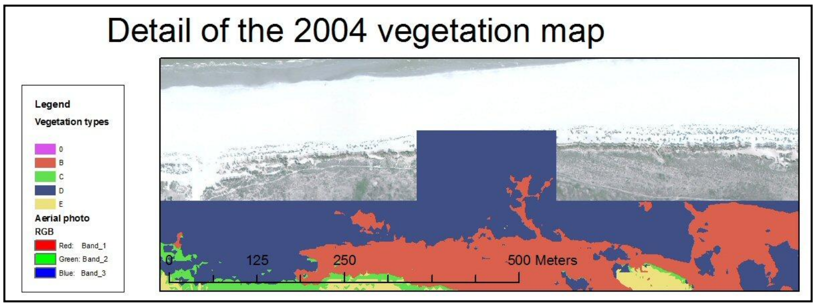
- Try to discover the different vegetation areas.

26. It is interesting to discover the different vegetation areas.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

27. The four types of vegetation have distinctive characteristics.				
Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

28. If you cannot make a distinction or if it is hard to make a distinction, what should in your opinion be improved?
Colour and structure of

- Navigate to the area as shown in the figure.



29. It is realistic to find these plants growing on the beach.				
Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree

30. It is realistic to find these plants growing on the north side of the dune near the beach.				
Strongly Disagree	Disagree	Neither agree nor disagree	Agree	Strongly Agree

31. The cloudy sky background improves the feeling of realism of the 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

32. This sky distracts me from the vegetation analysis task.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

The 2008 visualisation

Time: 20 min

- Click “Scene” in the menu bar on top. Then click “Go to terrain”. Select “Ameland 2008”. Click OK
- *The 2008 visualisation will now load. Please answer the next statement while it loads*

33. I’m curious to explore the 2008 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	Agree	**Strongly Agree**

- Click “Navigate in menu bar on top. Then click “Navigation style”. Select “Panoramic flyer”
- Put the 3D mouse aside and start navigating with your mouse. Ask for an explanation if the controls are not clear
- Move forwards to the vegetation and view it from above. Inspect the whole area.
- Try to discover the different vegetation areas.

34. It is interesting to move around in the 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	Agree	**Strongly Agree**

- Zoom in to the plants.

35. It is interesting to see the plants in detail.				
Strongly Disagree	Disagree	Neither agree nor disagree	Agree	**Strongly Agree**

- Try to discover the different vegetation areas.

36. It is interesting to discover the different vegetation areas.				
Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

- *If you failed to do these tasks with your regular mouse, you can do it again with the 3D mouse*

37. The four types of vegetation have distinctive characteristics.				
Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

38. If you cannot make a distinction or if it is hard to make a distinction, what should in your opinion be improved?
More realistic image looking from a distance

39. I prefer the 3D visualisation above the vegetation map.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

40. The 2D vegetation map gives a better overview of the distribution of the different vegetation areas compared to the 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

41. The 2D vegetation map gives a better overview of the distribution and abundance of the plant species.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

42. The 2D vegetation map gives a better overview of the vegetation changes over the years compared to the 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

Overall

Time: 20 min

43. The distribution of the plants over the research area or the vegetation areas is comparable to the real situation in the Ameland research area.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

44. What is not realistic? How should this be improved?
Not realistic: Hippophae present nearly everywhere, other species usually inconspicuous Improvements: more species, more variation in individual size

45. I understand how the 3D visualisation was created from the vegetation maps.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

46. Do you have comments on the process of creating a 3D visualisation out of the vegetation maps? Are there things wrong?
The overall idea is ok, implementation has to be more sophisticated. More species, more realistic distribution , more realistic colour etc.

47. It is easy to navigate in the 3D environment.					
3D mouse	Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree
Regular mouse	Strongly Disagree	Disagree	**Neither agree nor**	Agree	Strongly Agree

			disagree		

48. I was able to reach all the positions and locations I wanted to reach.					
3D mouse	Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree
Regular mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

49. It is easy to move up and down.					
3D mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree
Regular mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

50. It is easy to move left and right.					
3D mouse	Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree
Regular mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

51. It is easy to move forward and backward.					
3D mouse	Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree
Regular mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

52. It is easy to tilt forward and backward.					
3D mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree
Regular mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

53. I could get close enough to the plants to view all their details.					
3D mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree
Regular mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

54. The overview map on the bottom right was helpful.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

55. The north arrow was helpful.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

56. The white border in 2004 was helpful in the navigating process.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

57. It was easy to master the capabilities of the 3D mouse in the 3D visualisation.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

58. The panoramic flyer was intuitive to work with.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

59. It was easy to master the capabilities of the panoramic flyer.				
Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

60. Which navigation device is better?	
3D mouse	**panoramic flyer**

61. Would a 3D visualisation be helpful in your research?	
Yes	No

62. I want to see more or other information than the aerial photograph, such as information on ground water levels, chances on sea water intrusion, number of days the area is flooded etc.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

63. Are there other geographic datasets that you want to have projected on the DEM for analysis or extra information? Which ones?

64. What other possible uses could there be for 3D vegetation visualisation?
Visualisation of model output i.e changes over time

65. The 3D visualisation of vegetation matched my expectations.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

66. What differences were there between your expectations and experiences?
Still very much a teletubby landscape

67. This is a successful visualisation of the vegetation in the research area.				
Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

68. What is your overall opinion on this 3D visualisation of vegetation?
Please continue development: it is promising!

Expert test of the 3D visualisation of vegetation

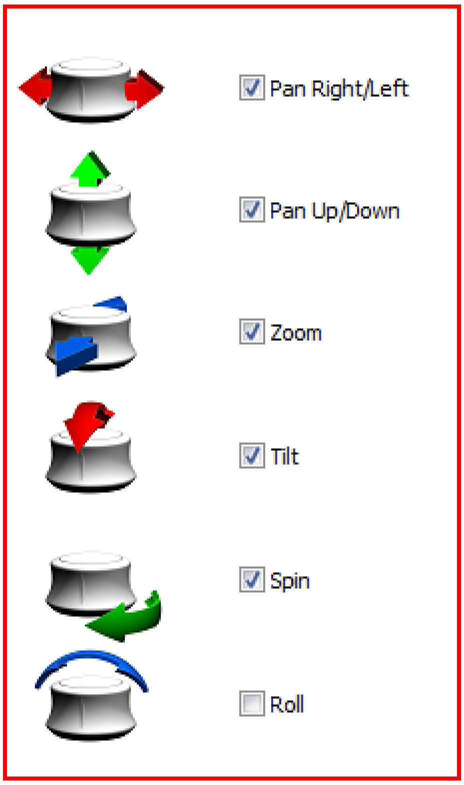
Expectations

1. **What do you expect from this 3D visualisation?**

I'm open to any suggestion, knowing it is rather difficult to make an abstract visualisation of the real world. Surprise me.

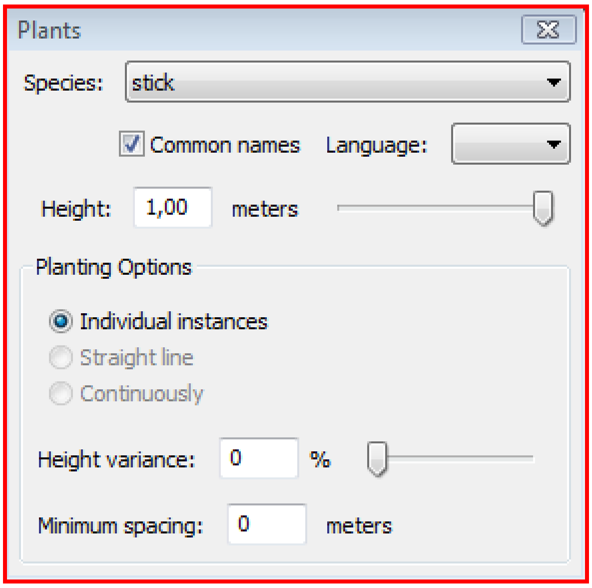
Moving around with the 3D mouse

You are going to use the 3Dconnexion Spacenavigator to move around in the 3D visualization. The figure on the left shows the possibilities with this mouse



- Pan right/left: you will move to the right or the left
- Pan up/down: you will move upward or downward
- Zoom: you will move forward or backward
- Tilt: your viewing and moving direction will go up or down
- Spin: Turn around your axis
- Roll: Disabled

How to measure a plant



- Click the green tree on the menu bar on top
- You can now plant every plant everywhere you want, which is the main goal of this function
- Now select from the drop down list at the top the specie called “Stick”
- Set the height to 1 meter
- Set the height variance to 0%
- Set the minimum spacing to 0 meters
- Move your mouse pointer to the location at which you want to measure a plant, you will see some guiding axes which will help you placing the stick
- When you’ve found the location, click and a 1 meter high red and white stick will be placed. One red or white part is 10cm.
- Move to a position at which you can compare the plant height with the stick and estimate the height of the plant.

The 2001 visualisation

Time: 10 min

- Move forwards to the vegetation and view it from above. Inspect the whole area.
- Try to discover the different vegetation areas.

2. It is interesting to move around in the 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

- Zoom in to the plants.

3. It is interesting to see the plants in detail.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

- Try to discover the different vegetation areas.

4. It is interesting to discover the different vegetation areas				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

5. The four types of vegetation have distinctive characteristics.				
Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

6. If you cannot make a distinction or if it is hard to make a distinction, what should in your opinion be improved?
The use of the 3D mouse needs some getting used to. And at least the shrub is not completely clear to distinguish to a species-level

The 2004 visualisation

Time: 20 min

- Click “Scene” in the menu bar on top. Then click “Go to terrain”. Select “Ameland 2004”. Click OK
- *The 2004 visualisation will now load. Please answer the next statement while it loads*

7. I’m curious to explore the 2004 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

- Move forwards to the vegetation and view it from above. Inspect the whole area.
- Try to discover the different vegetation areas.

8. It is interesting to move around in the 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

- Try to find a vegetation type which contains all the six plants
- Zoom in to the plants.

9. It is interesting to see the plants in detail.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

10. The plant species in the 3D visualisation are recognizable.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

11. If you cannot recognize all the plants, which one don’t you recognize?Give a description of the shape and colour
The one looking like a round disk on a stick (Armeria?) <-Color is not right The graslike bush (Junc Mar)

12. Estimate the size of the plants. The 3D plant models have a realistic size.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

13. Which ones are too large or too small?
Armeria is too big

14. The 3D plant models have realistic shapes.				
Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

15. Which plants do have unrealistic shapes?
The shrub of hyppophae has too big leaves and I miss the spikes

16. The 3D plant models have realistic colours.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

17. Which plants are unnatural coloured?
Mostly the shadow fades the colours, Armeria is to gray

- Try to discover the different vegetation areas.

18. It is interesting to discover the different vegetation areas				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

19. The four types of vegetation have distinctive characteristics.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

20. If you cannot make a distinction or if it is hard to make a distinction, what should in your opinion be improved?
the small number of plant species and small variation in spacing of individual plants makes it difficult to distinguish different vegetation types And there is not variation in the plant height within the species

21. The white border in the 2004 visualisation viewed from a large distance degrades the realism of the visualisation.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

22. The white border in the 2004 visualisation viewed from a close by (zoom in until you can clearly see the plant details) degrades the realism of the visualisation.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

The 2006 visualisation

Time: 20 min

- Click “Scene” in the menu bar on top. Then click “Go to terrain”. Select “Ameland 2006”. Click OK
- *The 2006 visualisation will now load. Please answer the next statement while it loads*

23. I’m curious to explore the 2006 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

- Move forwards to the vegetation and view it from above. Inspect the whole area.
- Try to discover the different vegetation areas.

24. It is interesting to move around in the 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

- Zoom in to the plants.

25. It is interesting to see the plants in detail.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

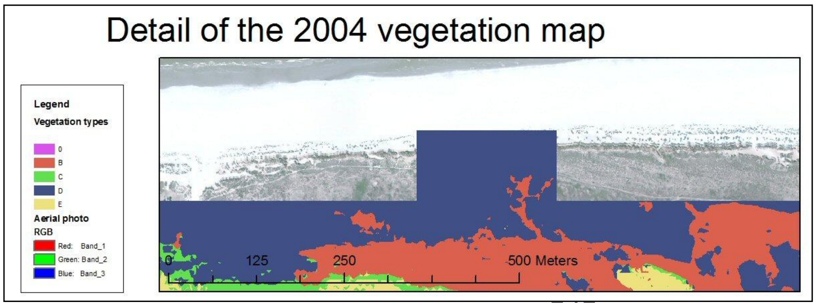
- Try to discover the different vegetation areas.

26. It is interesting to discover the different vegetation areas.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

27. The four types of vegetation have distinctive characteristics.				
Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

28. If you cannot make a distinction or if it is hard to make a distinction, what should in your opinion be improved?
Use limited number of species

- Navigate to the area as shown in the figure.



29. It is realistic to find these plants growing on the beach.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

30. It is realistic to find these plants growing on the north side of the dune near the beach.				
Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

31. The cloudy sky background improves the feeling of realism of the 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

32. This sky distracts me from the vegetation analysis task.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

The 2008 visualisation

Time: 20 min

- Click “Scene” in the menu bar on top. Then click “Go to terrain”. Select “Ameland 2008”. Click OK
- *The 2008 visualisation will now load. Please answer the next statement while it loads*

33. I’m curious to explore the 2008 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

- Click “Navigate in menu bar on top. Then click “Navigation style”. Select “Panoramic flyer”
- Put the 3D mouse aside and start navigating with your mouse. Ask for an explanation if the controls are not clear
- Move forwards to the vegetation and view it from above. Inspect the whole area.
- Try to discover the different vegetation areas.

34. It is interesting to move around in the 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

- Zoom in to the plants.

35. It is interesting to see the plants in detail.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

- Try to discover the different vegetation areas.

36. It is interesting to discover the different vegetation areas.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

- *If you failed to do these tasks with your regular mouse, you can do it again with the 3D mouse*

37. The four types of vegetation have distinctive characteristics.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

38. If you cannot make a distinction or if it is hard to make a distinction, what should in your opinion be improved?

39. I prefer the 3D visualisation above the vegetation map.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

40. The 2D vegetation map gives a better overview of the distribution of the different vegetation areas compared to the 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

41. The 2D vegetation map gives a better overview of the distribution and abundance of the plant species.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree** You need to have a specialist interest in vegetation science	Strongly Agree

42. The 2D vegetation map gives a better overview of the vegetation changes over the years compared to the 3D visualisation.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

Overall

Time: 20 min

43. The distribution of the plants over the research area or the vegetation areas is comparable to the real situation in the Ameland research area.				
Strongly Disagree	**Disagree**	Neither agree nor disagree	Agree	Strongly Agree

44. What is not realistic? How should this be improved?
Distribution should be interconnected with size and variation with species

45. I understand how the 3D visualisation was created from the vegetation maps.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

46. Do you have comments on the process of creating a 3D visualisation out of the vegetation maps? Are there things wrong?
The different species need a bit 'tuning' in colour and shape

47. It is easy to navigate in the 3D environment.					
3D mouse	Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree
Regular mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

48. I was able to reach all the positions and locations I wanted to reach.					
3D mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree
Regular mouse	Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

49. It is easy to move up and down.					
3D mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

Regular mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

50. It is easy to move left and right.					
3D mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree
Regular mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

51. It is easy to move forward and backward.					
3D mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree
Regular mouse	Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

52. It is easy to tilt forward and backward.					
3D mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree
Regular mouse	Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

53. I could get close enough to the plants to view all their details.					
3D mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree
Regular mouse	Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

54. The overview map on the bottom right was helpful.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

55. The north arrow was helpful.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

56. The white border in 2004 was helpful in the navigating process.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

57. It was easy to master the capabilities of the 3D mouse in the 3D visualisation.

Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

58. The panoramic flyer was intuitive to work with.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

59. It was easy to master the capabilities of the panoramic flyer.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree**	Strongly Agree

60. Which navigation device is better?	
3D mouse	**panoramic flyer**

61. Would a 3D visualisation be helpful in your research?	
Yes	No

62. I want to see more or other information than the aerial photograph, such as information on ground water levels, chances on sea water intrusion, number of days the area is flooded etc.				
Strongly Disagree	Disagree	Neither agree nor disagree	**Agree** As a option	Strongly Agree

63. Are there other geographic datasets that you want to have projected on the DEM for analysis or extra information? Which ones?
In bigger area's a topographic map (simple)

64. What other possible uses could there be for 3D vegetation visualisation?

Visualise modelling output for instance the vegetation part of the Natureplanner (combination of Move and Smart Sumo), and there are different forest development models. Extra the visualisation of nature development/restoration plans

65. The 3D visualisation of vegetation matched my expectations.				
Strongly Disagree	Disagree	**Neither agree nor disagree**	Agree	Strongly Agree

66. What differences were there between your expectations and experiences?
Structure of the vegetation, for instance the coarseness/grain size. Grassland has a different view or feel than a shrub vegetation

67. This is a successful visualisation of the vegetation in the research area.				
Strongly Disagree	**Disagree** Limited number of species	Neither agree nor disagree	Agree	Strongly Agree

68. What is your overall opinion on this 3D visualisation of vegetation?
An interesting tool for communication of modelling and planning output.

Appendix E: species.xml


```xml
<?xml version="1.0" encoding="utf-8"?>

<species-file file-format-version="1.1">
	<species name="juncumar" max_height="1">
		<common name="juncumar" />
		<appearance type="2" filename="juncumar.3ds" height="9" width="2.44" />
	</species>
	<species name="scirpmar" max_height="1">
		<common name="scirpmar" />
		<appearance type="2" filename="scirpmar.3ds" height="9" width="2.44" />
	</species>
	<species name="hipporha" max_height="1">
		<common name="hipporha" />
		<appearance type="2" filename="hipporha.3ds" height="9" width="2.44" />
	</species>
	<species name="armermar" max_height="0.4">
		<common name="armermar" />
		<appearance type="2" filename="armermar.3ds" height="9" width="2.44" />
	</species>
	<species name="triglmar" max_height="0.6">
		<common name="triglmar" />
		<appearance type="2" filename="triglmar.3ds" height="9" width="2.44" />
	</species>
	<species name="potenans" max_height="0.3">
		<common name="potenans" />
		<appearance type="2" filename="potentilla.3ds" height="9" width="2.44" />
	</species>
	<species name="stick" max_height="1">
		<common name="stick" />
		<appearance type="2" filename="stick3.3ds" height="1" width="1" />
	</species>
</species-file>
```

Appendix F: bioregions.txt

2001

bioregion1.0
types: 5
species: 4
    potenans 0.19792857
    hipporha 0.03785714
    scirpmar 0.00164286
    armermar 0.01
species: 1
    hipporha 0.025575
species: 1
    hipporha 0.0155125
species: 1
    hipporha 0.02882609
species: 0

2004

bioregion1.0
types: 5
species: 6
    potenans 0.18586207
    juncumar 0.0120689
    hipporha 0.03785714
    scirpmar 0.00164286
    triglmar 0.00003448
    armermar 0.01
species: 3
    potenans 0.01435135
    hipporha 0.08275676
    scirpmar 0.01135135
species: 2
    potenans 0.00003226
    hipporha 0.0326129
species: 1
    hipporha 0.03453488
species: 0

2006
bioregion1.0
types: 5
species: 5
    potenans 0.094137933
    juncumar 0.01206897
    hipporha 0.02572414
    scirpmar 0.00637931
    armermar 0.01
species: 3
    potenans 0.00724324
    hipporha 0.055
    scirpmar 0.01351351
species: 2
    potenans 0.00003226
    hipporha 0.03664516
species: 1
    hipporha 0.03067442
species: 0

2008
bioregion1.0
types: 5
species: 5
    potenans 0.16031429
    juncumar 0.0006
    hipporha 0.01274286
    scirpmar 0.01154286
    armermar 0.01
species: 3
    potenans 0.0491875
    hipporha 0.0385625
    scirpmar 0.00471875
species: 2
    potenans 0.00774194
    hipporha 0.05793548
species: 4
    potenans 0.00063415
    juncumar 0.00007317
    hipporha 0.03546341
    scirpmar 0.00002439
species: 0

Appendix G: CD containing the data

Contents

- Digital copy of this thesis
- Literature used for this thesis (see readme.doc)
- Input data (see readme.doc)
- 3D visualisation data (see readme.doc)
- Virtual Terrain Project installation file