# UNIVERSITY<sup>OF</sup> BIRMINGHAM

# **University of Birmingham Research Archive**

#### e-theses repository

This unpublished thesis/dissertation is copyright of the author and/or third parties. The intellectual property rights of the author or third parties in respect of this work are as defined by The Copyright Designs and Patents Act 1988 or as modified by any successor legislation.

Any use made of information contained in this thesis/dissertation must be in accordance with that legislation and must be properly acknowledged. Further distribution or reproduction in any format is prohibited without the permission of the copyright holder.

# 2<sup>nd</sup> of 4 files

# Chapters 2 to 3

# DEVELOPING ARTIFICIAL LIFE SIMULATIONS OF VEGETATION TO SUPPORT THE VIRTUAL RECONSTRUCTION OF ANCIENT LANDSCAPES

By

Eugene Ch'ng A thesis submitted to The University of Birmingham For the degree of DOCTOR OF PHILOSOPHY (PhD)

School of Engineering Department of Electronic, Electrical & Computer Engineering The University of Birmingham September 2006

# **Chapter 2**

# **Literature Review**

### 2.1. Introduction

Virtual Heritage and Artificial Life are two very new yet promising fields. This section targets specific areas related to the implementations of 'living' environments, the modelling and synthesis of life in alife, and vegetation pattern modelling in archaeology. The identification of the strength and weaknesses in related research will reveal gaps that could be bridged with better approaches for the reconstruction of an archaeological site. This section also discusses why alife is important in Virtual Heritage research. By learning the key principles in each of these areas and by developing novel models, ancient landscapes such as the submerged Shotton river valley could be digitally restored. The models applied in this Virtual Heritage research will then allow archaeologists a foundation for analysing and interpreting the impacts of the distribution of vegetations on Mesolithic cultures, which before the present time has never been achieved.

#### 2.2. Related Virtual Heritage Research

A review of Virtual Heritage research related to landscape reconstructions and Virtual Environments inhabited by living entities found a little more than ten examples. This may be due to the fact that Virtual Heritage research really only began in 1998. The other reason is that projects in these categories are scarce – there are not many Snowshoe Mountains available, and Stonehenge is unique in both time and space. These projects are also difficult to implement due to the limitations of technology in the past and the lack of personnel with required expertise. In recent years, however, software and hardware technologies for visualisation and content creating are becoming inexpensive and more available. Furthermore, user-oriented programming languages, software libraries and environments for generating 3D contents have eased the creation of interactive Virtual Environments. This section looks at the few examples of 'living' environments in related Virtual Heritage projects.

## 2.2.1. Landscapes and Natural Heritage

Virtual Heritage research in the past has attempted to model landscapes at present times as a means of conservation and education. A survey of literatures related to Virtual Heritage so far did not reveal any projects attempting to reconstruct or 'theorize' ancient landscapes that are non-existent as a result of geological changes or inaccessible due to geological limitations. The projects mentioned below derived their data mainly from current landscape conditions. No reconstructions related to submerged ancient landscapes were found in the review.

Virtual Stonehenge [34] was constructed for immersive kiosk-based demonstration. The optimised surface representations of each of the 80 stones and both the surrounding topography were built up manually from point data extrapolated from hundreds of stereo and aerial photographs, plus geographical and photogrammetric information generated in 1995 by English Heritage. With the heritage site protected from public access, English Heritage saw Virtual Reality as a possible solution to allow people to "walk" amongst the stones and experience the different textures and features in 3D, or be able to see the different lichens, the sword blade damage inflicted by Roman centurions and even graffiti carved in the form of a stylized signature by the famous architect Sir Christopher Wren. The Virtual Stonehenge used Sense8's WorldToolKit targeting the Intergraph platform with a VR4 headset. The simulation rendered an accurate night time sky by projecting the star positions onto a sphere surrounding the Stonehenge model from the celestial equator. Stonehenge first introduced the use of a 'living' environment (albeit a simple one) – the real-time sunrise effect.

Virtual Snowshoe [134] is an enhanced environment that uses real-time information to support the modelling of large-scale ecosystem climatic conditions based on live weather information and GIS terrain data. Refsland *et al.* defined an enhanced environment as "a mixture of virtual and real environmental information that is interconnected to provide a more realistic and meaningful interpretation of both the virtual and real environment that is ultimately greater than the individual experience." And discussed five major elements considered enhanced:

- 1. Real-time, enhanced information
- 2. Reduction in storage
- 3. Reduction in computational resources

- 4. Natural pulses and Rhythms
- Hybrid Integration of Visualisation-Simulation, Artificial Life, Game Industries, and Real-Time Environmental Interactivity

Three obstacles are given in the move towards an enhanced environment:

- 1. Insufficient computational power
- 2. Non-engaging, Non-immersive
- 3. Static environments

Virtual Snowshoe uses Epic's Unreal<sup>™</sup> games engine for the simulation within a common multimedia PC. The terrain is created from the conversion of a Digital Elevation Model (DEM) into heightmaps typically used for terrain generation in Unreal. Seasonal conditions of the landscape textures are colour-correction copies from aerial images from the National Aerial Photography Program (NAPP). Climate controllers are Web-based and integrated via HTML with SQL as a database and Macromedia's ColdFusion<sup>™</sup> as the language. The sun controller has three modes: Real-Time, auto-step, and manual. The simulation uses several Web-based real-time streaming data sources for establishing streaming information related to weather, hydrology, snowfall, temperature, snow coverage, and slope conditions.

The Virtual Villages of Shirakawa-go [38] propose environmental simulation of weather to see the long-term cause and effect of climatic conditions and to observe what the dynamical representation of the effects of snow and wind have on the Gassho-Zukuri House. Shirakawa-go, is located within 45.6 hectares of land in northern Gifu Prefecture and is one of the sites registered as UNESCO's world heritage. For the virtual reconstruction, the project was created in three parts: The panorama of Shirakawa-go and its surrounding area, the Minkaen part, an area within Shirakawa-go that occupies approximately 5.8 hectares, and a detailed view of a typical Gasshozukuri house in Minkaen. The 45.6 hectares of the landscape were created by generating 3D models and textures from aerial photographs taken from an altitude of 22,000 metres. 3D Minkaen was created using drawings to establish the area's geographical data and colour images from aerial photographs, taken from a helicopter at an altitude of 750 metres was used as textures. The modelling of Minkaen uses OpenInventor<sup>TM</sup> format. An evaluation function technique was used for optimising the 3D terrains into a real-time capable model. In the third part, the interior and exterior of the 3D Gassho-zukuri houses was constructed. Two proposals were made for a 'living' environment. For environmental simulation, the first proposal considered artificially changing the geographical configuration and climatic conditions of the area. For the second proposal, dynamical representation of the effects that snow and wind have on the Gassho-zukuri houses are considered.

Virtual Florida Everglades [126] aim to create a cost-effective, freestanding and ecologically themed virtual reality simulation using the Unreal engine in a standard PC Windows NT/98 platform. The Everglades National Park is a 1-million acre park in Florida, USA; only parts of the Everglades were simulated using the atmospheric effects in the engine.

The review showed that, except for Virtual Stonehenge and the Virtual Villages of Shirakawago, all other landscape reconstructions employed the Unreal<sup>TM</sup> games engine as their simulation platform. With regards to the 'livingness' of the environment, Virtual Stonehenge and Virtual Snowshoe introduced the linking of real-time external effects with that simulated in the Virtual Environment.

#### 2.2.2. Living Entities in Virtual Heritage Environments

Aside from landscape reconstructions, work has also been carried out on animating certain forms of living beings as inhabitants of Virtual Environments. Strictly speaking, an entity residing in a virtual world that is considered 'living' should at least possess some characteristic behaviour that allows it to respond to the environment as any natural organisms would from other living entities or user interaction. However, a virtual entity that has the capability of responding to physics-based simulations, although responsive, cannot be considered as part of this category. For example, a ball that rolls down a virtual terrain as a result of user interaction cannot be in the same category, neither can a bell that gives a sound when its associated button is pressed. In Virtual Heritage, a living entity must *in the least* have 'life', appear to be living, or possess the simplest intelligence that enables it to make uncomplicated decisions. In this case, virtual birds that flock together and 'flee' from threats can be considered 'living', so is a real-time virtual character that accomplishes certain tasks in his/her task environment. More advanced virtual life forms are those that grow, mate, reproduce, compete, survive, evolve, and cooperate with other organisms.

Nevertheless, some projects that incorporate non-responsive avatars are also mentioned here. This section reviews research in 'living' Virtual Heritage environments.

The Virtual Living Kinka Kuji Temple [127] uses the Unreal<sup>TM</sup> games engine as a simulation platform for the Virtual Environment. A behavioural module was developed for polling company stock price data to give position and behavioural information to alife entities in the Virtual Environment. The simulation uses the natural computing power of emergent properties and chaos found in live data streams (NASDAQ stock market) to enliven the artificial fireflies inhabiting the neighbouring gardens of the Virtual Kinka Kuji Temple based in Kyoto, Japan.

Virtual Snowshoe [134] used the NASDAQ stock market for the simulation of living entities. Using the Unreal<sup>TM</sup> engine, an existing actor class was used to create alife birds that were integrated into the system with a complexity-based rule set that defined weather conditions conducive for flight. For more natural behaviour, data from the stock market was polled every minute to dictate how "energetic" the alife bird will be – positive for energetic, and *vice versa*.

In Virtual Florida Everglades [126], the extensible subsystem of the Unreal<sup>TM</sup> engine using Object-Oriented C++ was used for making behavioural changes for characters in the engine. The 3D egret created in external modelling package and imported into Unreal<sup>TM</sup> uses *state programming models* for simple behavioural patterns like foraging, patrolling, sleeping, etc. Environmental triggers and a simple random seed algorithm was used to determine which patterns manifest themselves and predetermined player-attitude models (friendly, hostile, and reclusive) control other factors of the character. The addition of the virtual egret and a simple behavioural model adds reality to the simulation.

The addition of virtual avatars – representation of users of a Virtual Environment or characters inhabiting the environment has become quite popular in recent years. An example is Virtual Notre Dame [128] which created avatars – virtual monks using the Unreal engine that were intended to guide visitors around the cathedral, leading them to places of interests, had the project been completed. Two other works based on single tour guide in cathedrals are Frohlich *et al.* [135] and Behr *et al.*'s [96] virtual cathedral in Siena. Others such as Foni *et al.* [136] and Papagiannakis *et al.* [137] added a small number of worshipers into virtual mosque. Sanders *et al.* [138]

reconstructed the archaeological site of the Northwest Palace of Ashur-nasir-pal II, incorporating a 3D avatar of King Ashur himself for presenting the historical information of the palace. Song *et al.* [98] recreated Peranakans – descendants of an early Chinese community that evolved as a result of intermarriages between early Chinese settlers and the indigenous Malay in the Malay archipelago since the 17<sup>th</sup> century. The Virtual Peranakans were built to guide visitors through the environment and provide historical information. A project that simulates real-time character animation and dynamics in ancient Olympic games uses virtual athletes [139]. Although the virtual athletes appeared living, they were non-responsive avatars. However, the users could themselves participate in some of the games, which use simulated aerodynamics.

Simulation of crowds in large settings has also been developed. Ryder, Flack and Day [140] implemented an adaptive crowd behaviour system for aiding real-time rendering of a cultural heritage. The approach develops an algorithm that influences crowd dynamics to maintain a rendering frame rate in Boids-based self-steering crowds. However, the virtual humans have a limited understanding of their environments, such as differences between the road and a pavement, which when developed, will aid realism to the project. Ulicny and Thalmann [141] presented a 3D animated crowd performing virtual prayers. Ciechomski *et al.* [142] on the other hand, developed a reactive behavioural engine to simulate large crowds in a virtual audience. In the virtual audience, characters possess different emotional states, social classes, and genders.

At the time of writing, there is only one research on the reconstruction of an ancient life form in Virtual Heritage research. Miyagawa *et al.* [166] reconstructed the virtual space of Ammonites. However, the reconstructed entity is static and non-living.

### 2.3. Artificial Life

There are limited examples of implementations of living entities in Virtual Heritage. In the field of Artificial Life however, a great number of research are based on the modelling and the synthesis of life. Artificial Life research bestows life in the form of simple agents that react to events, evolve over generations, mate, reproduce, compete or cooperate in simulated environments.

# 2.3.1. Studies in Artificial Life

Artificial Life research is divided into two main groups. The *Strong alife* position suggests that "life is a process which can be abstracted away from any particular medium" (John von Neumann) and can be created by the use of inorganic matter via some simple initial conditions or simple mechanical rules. The *Weak alife* position suggests that life cannot be generated outside of a carbon-based chemical solution but its processes could be *understood* by mimicking it in computer simulations.

Bedau [160] identified the three branches of alife:

- 1. *Soft* alife creates simulations or other purely digital constructions that exhibit life-like behaviour
- 2. Hard alife produces hardware implementations of life-like systems
- 3. Wet alife synthesises living systems out of biochemical substances

The work in alife addresses two issues:

- 1. The study of life beyond the carbon-chain chemistry in biological life
- 2. The application of the principles of life for problem solving

Biology is the scientific study of carbon-based life forms. The fundamental obstacle in theoretical biology is that it is impossible to derive general principles from single examples. In order to derive general theories and to distinguish the essential properties of life, comparisons had to be made from many instances of life. Time is also an obstacle. The study of the life-cycles of organisms and their genetic descent requires the element of time. The other factor is data-noise. The compounds of data that can be gathered in the study of life inevitably results in information noises. This obstacle frustrates analysis of matter that requires unpolluted datasets. Artificial Life resolves these issues by creating alternative life-forms within computers. Computer simulation has permitted a new approach to the study of evolution and natural systems. According to Mitchell [153], simulation can be controlled, repeated to see how the modification of certain parameters changes the behaviour of the simulation, and run for many simulated generations. Such great control over synthesised life within computers has given researchers the means to eliminate the

limitations of time. It has also allowed the omission of information noises by filtering parameters that are not required so that a better understanding of life can be realised as a result of an unpolluted computer generated environment.

According to Christopher Langton, Artificial Life is "the study of synthetic systems that exhibit behaviors characteristic of natural living systems. It complements the traditional biological sciences concerned with the analysis of living organisms by attempting to synthesise life-like behavior within computers and other artificial media. By extending the empirical foundation upon which biology is based beyond the carbon-chain life that evolved on Earth, Artificial Life can contribute to theoretical biology by locating life-as-we-know-it within the larger picture of life-as-it-could-be" [2]. Studies in alife are similar to biology – alife is an experimental science. It attempts to understand the mechanisms behind living systems by synthesising them so that the structure and function of these systems may be understood and applied. Langton again states that "By extending the horizons of empirical research in biology beyond the territory currently circumscribed by life-as-we-know-it, the study of Artificial Life gives us access to the domain of life-as-it-could-be, and it is within this vastly larger domain that we must ground general theories of biology and in which we will discover novel and practical applications of biology in our engineering endeavors."

## 2.3.2. Emergence and the Principles of Artificial Life

Artificial Life is concerned with generating life-like behaviours within computers. Since the study focuses on the behaviours of life, it involves identifying the intrinsic mechanisms that generate such behaviours. These mechanisms are often very simple rules within an organism out of which complex behaviour emerges. Or on a higher level, the mechanism itself may be the simple behaviours of an organism. Together as cooperative entities, these organisms worked together as a larger 'organism' for the survival of the colony, yet from very basic pre-programmed rules in the monotony or variety of individual behaviours. The phenomena or intelligence that emerges as a result of the simple interaction between individual entities is called *emergence* [157, 158], a central concept supporting studies in alife.

Systems that exhibit emergent behaviours are commonly expressed in the sentence "the whole is greater than the sum of its parts" [156]. The term emergence was first used by an English philosopher G.H. Lewes [167] over a hundred years ago and has been subsequently studied in philosophy [168-171]. However, the process that issued in emergent behaviour or property was unknown to them until the advent of computers and the initiation of the theory of complexity [155, 172, 173] coupled with experiments on Cellular Automata (CA) [156, 161, 174-176]. Studies in CA showed that simple rules in computer agents could give rise to complex behaviours. A particular CA 'Life rule' [177] invented by John Conway in the 1970s called the Game of Life demonstrated the idea of emergence where simple interactions between entities resulted in objects and patterns that are surprising and counter-intuitive. Referring to the definition of the term 'emergence', John Holland [157], a pioneer in complex systems and nonlinear science advised that "It is unlikely that a topic as complicated as emergence will submit meekly to a concise definition, and I have no such definition to offer", however, he adds that "The hallmark of emergence is this sense of much coming from little... where the behaviour of the whole is much more complex than the behaviour of the parts." Another definition [178] states that emergence is "...the process by which patterns or global-level structures arise from interactive local-level processes. This "structure" or "pattern" cannot be understood or predicted from the behaviour or properties of the component units alone." In a more elaborate sentence given by Stacey [179], "Emergence is the production of global patterns of behaviour by agents in a complex system interacting according to their own local rules of behaviour, without intending the global patterns of behaviour that come about. In emergence, global patterns cannot be predicted from the local rules of behaviour that produce them. To put it another way, global patterns cannot be reduced to individual behaviour."

The success of alife in problem solving is identified by the possibility of emulating nature's properties of *decentralisation*, *self-organisation*, *self-assembly*, *self-producing*, and *self-reproduction*, all of which are key concepts in the science of alife. A decentralised system [180] relies on lateral relationships for decision making instead of on the hierarchical structure of command or force. *Self-organisation* [156, 181] refers to systems that manage itself and increases in productivity automatically without guidance from an external source. In systems with characteristics of *self-assembly*, patterns are seen to form from simple disordered components. *Self-producing* or *autopoiesis* [182] connotes the idea that certain types of system continuously produce their constituents, their own components, which then participate in these same production processes. An autopoietic system has a circular organisation, which closes on itself, its outputs

becoming its own inputs. Such systems possess a degree of autonomy from their environment since their own operations ensure, within limits, their future continuation. In *Self-replication [174, 183, 184]*, entities makes copies of themselves.

Resnick [180] presents evidence of a trend of decentralisation across important domains in nature, organisation, society, science, and philosophy. He states that orderly patterns can arise from simple, local interactions and that many things are "organised without an organisation, coordinated without a coordinator". In the same way, Farmer and Packard [185] noted that in self-organising systems, patterns emerge out of lower-level randomness. Furthermore, Charles Darwin [186] asserted that order and complexity arises from decentralised processes of variation and selection. Langton [159], the founder of alife, stated that in order to model complex systems like life, the most promising approach is to dispense "with the notion of a centralised global controller" and to focus "on mechanisms for the distributed control of behaviour".

The characteristics inherent in many decentralised systems are nonlinear, and the nonlinearity, as characterised by natural and alife systems is what makes the outcome more than the sum of their parts – forming dynamic patterns, collective intelligence and unpredictable behaviours from the lateral interactions between similar entities. This is the difference between the bottom-up approach in alife and the top-down methods in AI and many older man-made systems. By employing the bottom-up approach observed in nature, not only can we discover how certain systems work, but many complex problems previously impenetrable with top-down methods can now be readily solved.

## 2.3.3. Artificial Life and Its Applications

Concepts central to Artificial Life have not only been used for studying biology but in the discipline's formative years as a new science has seen a tremendous increase in the applications of its principles for solving real world problems. In the work presented here, it is observed that the increase is due to the fact that the principles of alife simply work in real world situations. The reason for the functional cause does not entirely credit the ability of humans as a higher being capable of creating new ways for solving problems in their domains, but in their ability to learn from nature by emulating nature's way of problem solving. After all, problem solving is intrinsic in

nature. The following lays the foundation for vegetation modelling by explaining the principles of alife research from example studies. Finally, the applications of alife in various domains are summarised.

Social insects such as bees and especially ants in Gordon's study [187] are very good examples of models of decentralisation. As an individual unit, an insect accomplishes very little due to its simple state, but as a colony the simple rules built into the genes of each insect collectively achieve an intelligence and personality that displays nature's best example of self-organisation. In the ant colony, the queen is not an authoritarian figure and does not decide the tasks of each worker ant due to the fact that the queen's quarter is separated by several metres of intricate tunnels and chambers and thousands of ants, rendering her physically impossible to direct each worker ant's decision within the colony. But it is interesting to note that in dangerous circumstances, the rule of keeping the queen safe in the gene pool of the ants make them remove the queen to the escape hatch in an organised behaviour issuing from collective decision making. Self-organising behaviour is also seen in the separation of food, garbage and deceased ants in the colony. In a collective decision the garbage dump and cemetery are situated apart by the ants in Gordon's observation, with the cemetery situated at exactly the point that is furthest from the colony, solving spatial mathematical problems without a central command of intelligence.

The slime mould [188-191] are thousands of distinct single-celled units moving as separate individuals from their comrades, oscillating between being a single celled creature and a swarm. Under suitable conditions, the single-celled organisms combined into a single, larger organism scavenging for food on the ground. In less hospitable conditions, the slime mould lives as a single organism. While being fairly simple as a single celled organism, the slime mould collectively displays an intriguing example of coordinated swarm behaviour via the individual release of a common substance called acrasin (or cyclic AMP). In a study [191], the slime mould was found to be capable of finding the shortest possible route through a maze. In normal circumstances, the slime mould spreads out its network of tube-like legs, or pseudopodia to fill all available space. But when two pieces of food were placed at separate exit points in the maze, the organism squeezed its entire body between the two nutrients, adopting the shortest possible route, thus solving the maze. The aggregate slime mould changes its shape and maximises its foraging efficiency to increase its chances of survival. The slime mould aggregation is recognised as a classic case study of bottom-up behaviour.

Swarms in nature are not the only examples of decentralised self-organising systems. In fact, decentralisation can be seen at a higher level in social systems such as the clustering of communities and businesses that emerged as cities. It is observed that city planners do not assign certain quarters to different races or statuses, rather, communities evolved and formed based on preferential rules and factors such as affordability, availability, and influence of religion, cultures, etc, that are intertwined in a way that some changes in certain factors necessarily effects the ecosystem of the city over time. The variable prices of residential and commercial properties in a city are not necessarily a decision by top-level city planners, but is very much influenced by factors from a bottom-up perspective. At the social level, the ecosystem of people-relationships is formed in the same way without a central command of who is to be associated with whom. Patterns of automobiles on traffic jams are caused by the local interaction of neighbouring cars accelerating and decelerating in order to maintain a safe distance.

From the examples given, the observation is that as long as we can find the principle rules inherent in these systems coupled with programming prowess, any variables of the physical system can be digitised and its characteristics synthesised.

Already researchers have employed nature's self-organisation for solving problems. In Swarm Smarts [192] software agents mimicking models of ants and social insects were used to solve complex problems such as the rerouting of traffic in a busy telecommunications network. The pheromone trails left by ants enabled them to forage efficiently. In a situation where two ants leave the nest at the same time, with each taking a different route. The ant that took the shorter path will return first, leaving the trail with twice as much pheromone. Since the pheromone has increased in the shorter route, it will attract other ants more than the longer route will. Therefore, the pheromone trails enable the ants to raid the nearest available food sources, as supplies dwindle, the ants begin raiding food sources that are in the next shortest route. In network traffic, if a portion of the shortest path between two locations is congested (a congested path being a depleted food source), the software agents can reroute automatically in a manner that is similar to how ants raid different food sources. Although the interactions between these ants are simple, together they can solve difficult problems.

Certain ant species recruit nest mates to help when a single ant cannot retrieve a large prey. During the initial period that may last a few minutes, the ants change their positions and alignments around the object until they are able to move the prey towards their nest. In an experiment [193], a group of researchers inspired by the way ants work, programmed robots without using complex behaviours. Robots are assigned to push an illuminated circular box towards a light source. Each robot acted independently, does not communicate with other ants, but followed a set of simple instructions: find the box, make contact with it, position yourself so that the box is between you and the goal, then push the box towards the goal. Collectively, the group was able to accomplish its goal without communicating with each other. This example showed that simple rules in separate units can accomplish tasks without the need for complex behaviours, thereby eliminating the need for huge computing resources.

In a honey bee colony, depending on their age, individuals specialise in specific tasks. Older bees tend to be foragers for the hive, but when food is scarce, younger nurse bees will forage. Using the bee behaviours, scientists reported in the article *Swarm Smarts* [192] devised a technique for scheduling paint booths in a truck factory. Each booth is like an artificial bee, and individuals perform the tasks for which it is specialised until it perceives an important need to perform other tasks. By emulating how the bee colony works, the system enables the paint booths in determining their own schedules. The outcome is a higher efficiency – few colour changes as compared to a centralised computer control.

The flocking [194] and schooling [195-199] behaviour of animals, birds and fish have been studied extensively in the past not only for AI behaviour generation in movies and the games and entertainment industries (many games engines today uses flocking and schooling algorithms) [200], but also for assistance in tasks that require coordinated movements [201-203]. Synthesising these dynamic systems require only simple rules and states in each alife agent. In schooling fishes, the rules of schooling are a consequence of the tendency of each fish to avoid others that are too close. They align their bodies to those at intermediate distances, and move towards others that are far away. In imitating flocks of birds, physics and gravity are not taken into account in the design. Instead, three sets of simple rules (separation, alignment and cohesion) are observed and distilled from the patterns into program codes for the simulation, resulting in a flocking behaviour. Life is "a property of the organisation of matter" and "living organisms are nothing more than complex biochemical machines" [163, 204]. Such definitions gave a notion of life that is wholly

materialistic, "involving no soul, vital force, or essence" [205]. Stephen Wolfram, the creator of Mathematica<sup>TM</sup> has also studied and demonstrated the potentials of simple rules as published in the *New Kind of Science* [206]. These concepts are practically important to the way in which vegetation can be modelled.

These days, emerging technologies cannot do without the principles central to the science of alife. A good example is NASA's Institute for Advanced Concepts' hopping microbots for finding life forms on Mars and other terrestrial bodies. Swarms of these microbots could be released onto the surface of Mars for reconnaissance and sensing, imaging, and other scientific functions that may result in the loss of a large percentage of the units but still have a network that could be functional. The tennis sized robots relate to each other using very simple rules, but produces a great deal of flexibility in their collective behaviour that enables them to meet the demands of unpredictable and hazardous terrains. Compared to a single complex robot doing similar tasks, the decentralised units can accomplish much more.

In a recent review, Kim and Cho [207] surveyed the applications of Artificial Life, the creation of synthetic life on computers to study, simulate, and understand living systems. The study showed that alife research today synthesises life more than analyses it. The survey comprised some 180 applications in alife includes robot control, robot manufacturing, practical robots, computer graphics, natural phenomenon modelling, entertainment, games, music, economics, Internet, information processing, industrial design, simulation software, electronics, security, data mining, and telecommunications. They found Evolutionary Computation to be the most popular method. The also found that recent works in swarm intelligence, artificial immune network, and agent-based modelling have also produced successful results. The survey also revealed the common properties found in successful applications of alife:

- 1. Achieving similar behaviour to biological creatures
- 2. The details of the final results have not been described before experimentation
- 3. Designing without expert knowledge
- 4. Interdisciplinary cooperation
- 5. Huge computational requirement
- 6. Evolution based on simple primitive shapes such as box and pipe
- 7. Computer simulation

# 2.4. Artificial Life and Vegetation Modelling

Literature in vegetation modelling related to alife is scarce. A survey revealed only a handful of articles of which only several are useful for simulation in large landscapes. This is, of course, to be expected as the science of alife is relatively new for addressing this particular direction of research.

In the Artificial Life context, there are at least three methods for modelling vegetation using the bottom-up, decentralised approach. One method is to model the plant from the interacting cells forming its structures; another is to model the intermediate plant's vascular structure and its growth and interaction within a localised position. The third approach is to model the plant as a reactive agent - a complete unit that responds to ecological factors in order to determine the local and global distribution of vegetation on landscapes. To date, two approaches have been attempted. L-System or particle-based structural models are very popular and are frequently used to model the structure of trees, flowers, and roots of plants in computer graphics. Agent-based models are few, but seemed to be more suited to large landscapes.

### 2.4.1. Digital Plant Models

Structural growth and branching patterns of plants are well researched. The first computer model of tree structure was introduced by Honda [208]. Other early models of plants are based on fractals [209-211]. Within the fractals domain, a very realistic branching pattern approach is Oppenheimer's model [211]. Oppenheimer presents a fractal computer model of branching objects, which generates very realistic pictures of simple orderly plants, complex gnarled trees, leaves, and vein systems. Work in modelling the branching patterns of plants later developed through formal specification resulting in the Lindenmayer systems (L-Systems). L-Systems introduced in [212, 213] comprise sets of formal grammar (rules and symbols) that generate complex sentences from primitive components. L-Systems were first used for modelling plant structures in computer graphics [214]. L-System was subsequently improved [215]. Since then, L-systems have been widely used for describing the growth and developments of spatial structures of plants (e.g., [216-220]). Methods other than the early fractals and the popular L-Systems have also been developed [221-225], which contributed towards synthesising images of plants using computer graphics.

Computer graphics models of plants, although realistic, did not take into account the effects of environmental factors on plant developments. Therefore its uses were limited only to beautiful illustrations in computer graphics.

#### 2.4.2. Cell Models

An ideal solution for the *Strong alife* type of work is to develop the growth of a plant from the cells upwards forming organs, structures, and finally the plant itself. Although this is possible, there have been no such developments.

#### 2.4.3. Structural Models

Useful models of plants required interaction with their environment. Attempts to simulate interaction between plants and their environments have resulted in the extension of L-System. Open L-Systems [226] were developed to allow interaction between plants and their environment. In Open L-System, a bi-directional information exchange between plants and their environment is possible. Competition is threefold – branches are limited by collisions, roots compete for water in the soil, and there is competition within and between trees for sunlight.

Particle systems for modelling plant structures were used for the first time by Reeves and Blau [227]. Arvo and Kirk [228] and later Greene [229, 230] simulated climbing plants using the same method. Particles were also used for modelling climbing plants as systems of oriented particles that are able to sense their environment [231], but mainly with stationary objects. Algorithms for radiant energy transfers (lighting simulation) affecting plant growth have also been studied [232]. Others like Hanan *et al.* [233], modelled insect movement and the damage and development of 3D structures of a plant.

It is known that models based on the structures of plant growth require heavy computing power. This is the reason why most structural plant models are static renderings or image sequences of it. For vegetation modelling in large landscapes and Virtual Environments, techniques using highlevel models are necessary.

## 2.4.4. Agent-Based Models

One of the approach in agent-based techniques is called *collaborative agents* [145]. Collaborative agents emphasises autonomy and cooperation with other agents in order to perform tasks for their owners in open and time-constrained multi-agent environments. In a competitive environment however, collaborative agents can become non-collaborative and even intimidating when species compete for resources in order to survive and leave progenies. A competitive vegetation landscape is categorised as such. From a global point of view, vegetation agents collaborate by competition so that the task of distributing vegetation across a landscape is accomplished. But from a local perspective, they compete against each other for survival in an uncooperative way. This section analyses some of the vegetation agent-based models in static and real-time rendering environment.

Modelling and realistic rendering of scenes with thousands of plants have been attempted. Deussen et al. [227] introduces a pipeline of tools for modelling and rendering of plants on terrain. The pipeline is composed of two levels of simulation – modelling and rendering. The modelling aspect of plant distribution can either be determined by hand (using a set of grey-level images for defining the spatial distribution of plant densities), by ecosystem simulation, or by a combination of both techniques. Ecosystem simulation uses the Open L-System where each plant (represented as circles) is connected to another in a branching pattern characteristic of L-Systems. The simulation of competition is simple – if two circles intersect, the smaller plant dies, and plants reaching a set size limit are considered old and is eliminated. The model also manipulates the plant population and distribution using a simplified self-thinning [228] algorithm based on a model of Firbank and Watkinson [229] for simulating the phenomenon in plant population dynamics. The outcome of the ecosystem simulation is rendered using third-party render engines with associated plant models from XFrog<sup>TM</sup> [230]. Deussen et al.'s method is partially agent-based with L-System as a framework connecting each plant. Since the population and distribution of plants are largely manipulated, the basic autonomy of plant species is dissimilar to that observed in natural systems, which by nature is bottom-up. Real-time rendering using the approach is impossible as it consumes huge resources. For example, the rendering of a single stream scene in Deassen *et al.*'s model took three days and, the time taken even on a 195 MHz R10000 8-processor Silicon Graphics Onxy with 768MB RAM were 75 minutes. In Deussen et al.'s project, ecosystem factors were not considered in the model.

Lane and Prusinkiewicz [238] introduce a local-to-global and a global-to-local approach for generating spatial distribution of plant species. In the former approach, plants are planted, grow, and interact in a way that leads to a pattern of distribution. In the second approach, plant distributions are specified using gray-scale images before the system generates the corresponding imagery. Only the former approach is evaluated here as it is related to the principles of alife. The local-to-global approach is an extension of Deussen et al.'s work [234] mentioned previously. While Deussen et al.'s approach uses self-thinning, Lane and Prusinkiewicz extended the previous L-System with a succession model. In the self-thinning method, the parameter c is used for interaction between plants, which sets c=1 if the plant is not dominated and to  $\theta$  if the plant is dominated. The succession model is a closer approach to plant interaction in the real world. In the algorithm, new plants are added in every time steps with local propagation – sowing new plants near plants of the same species. Shade competition replaces the two state domination parameter by introducing a probability of *1-shaded[sp]*, where *sp* is a plant identifier, and *shaded[sp]* is the shade tolerance of the plant, measured by how likely it is to survive in shadow. Senescence of plants is modelled by introducing a survival probability measure *oldage[sp]*. In the system, a plant that does not survive dies and is removed from the community. In both the self-thinning and succession model, environmental factors are not considered. Rendering methods are similar in both models.

Benes and Cordoba [231] presented an ecosystem for the cultivation of virtual plants via procedural agents. The agent (a virtual farmer) can seed new plants, pull out weeds, water plants, and communicate by message passing to distribute their tasks. In Benes and Cordoba's work, an ecosystem is defined as "a set of individual plants in different stages of development" and "is a Virtual Environment represented as a 2D continuous area inhabited by virtual plants". Plant models are limited to English daisy, wheat, grasses, yellow tulip, and different procedurally generated trees obtained from the Strands model [232]. Plants in the ecosystem are influenced by other plants, external resources, and procedural agents. The seeding of the terrain can either be random or interactive via some drawing programs using colour as corresponding plant species. Seeded plants grow, compete, reproduce, and die. Although the authors claimed that plants are influenced by competition and external sources, the methods are not explained. The rendering uses Povray<sup>TM</sup> [233], a static renderer. The total rendering time for a single scene in resolution 800 x 600 pixels with antialising on a 2GHz IBM PC was 24 minutes. A study on non-interactive

rendering for plant clustering using Povray<sup>™</sup> by one of the authors has also been demonstrated [234].

The Nerve Garden, a real-time agent-based model [235], whilst claiming to exhibit properties of growth, decay, and energy transfer reminiscent of a simple ecosystem, presents a somewhat primitive solution from an alife perspective since it does not support plant growth or interaction between plants and the environment [133]. Damer's project is a work in progress using VRML 2.0 over the Internet for demonstrating a multi-user alife collaborative virtual world.

A model inspired by natural systems suited to large landscape vegetation distribution is Lange *et al*'s [236] approach. Lange *et al*'s model uses a growth simulator within an abiotic environment. Each plant interacts with two input fluxes – energy and a growth-limiting nutrient. The actual growth of each tree is derived from local competition for energy and nutrients. Evolutionary effects are included by random mutations of parameters related to height growth strategies of individual trees.

From the evaluation, certain fundamental principles required to properly synthesise behaviours of plant species were found to be either partial or lacking. It was discovered that no single system mentioned above collectively tackle these issues and therefore could not have been sufficiently accurate for plant synthesis. Furthermore, rendering of most systems are static imageries, posing a difficult problem when research in Virtual Heritage requires interactive media. The present research, then, seeks to address the issues that are partial and lacking as listed below:

- 1. Generic vegetation model capable of including all vegetation types
- 2. Individual plant life cycle seed, seedling, young, mature, and old
- 3. Generic plant life cycle growth, survival, competition, and reproduction
- 4. Vegetation forms (trees, shrubs, herbs, grass, and etc)
- 5. Seasonal differences (evergreen, deciduous)
- 6. Competitions based on vegetation types canopy, density of leaves, height, and vegetation types
- 7. Competition for space and sunlight
- 8. Nutrient accessibility

- Adaptability to ecological factors and resources sunlight, temperature, carbon dioxide, altitude, soil, hydrology, and etc)
- 10. Ground conditions soil acidity, soil depth, soil textures, ground slopes, and etc

#### 2.5. GIS and Large-Scale Vegetation Pattern Modelling

Large-scale vegetation pattern modelling techniques in archaeology are quite primitive and not as superlative as the models described in the previous section. Models for predicting past, present, and future vegetation distribution on landscapes have in the past appeared in both archaeology and in studies of forest succession.

Before advanced computing systems became available to archaeological research, reconstructing prehistoric environments depended mainly on data from palynology [12, 237] and is still a crucial source of data to this day [238-240]. When GIS came into the scene in landscape archaeology, the potentials of merging various environmental variables as base maps (image-based information maps such as soil types, altitudinal limits, etc) in order to determine the likelihood of vegetation distribution (mostly woodlands) at a certain historical period (sequences) became dominant in the field. However, GIS although powerful has its limitations with regards to cognitive representations, temporal analysis, three-dimensional analysis, and the accuracy of the represented model (see section 1.2.4 in Chapter One). GIS-based approaches are mostly linear and top-down. Using GIS-based systems for determining vegetation patterns can be compared to manually placing vegetations on the terrains by cross referencing the terrain data and the vegetation preference, except that the process is automated and accelerated using computer algorithms.

A very prominent work is Penny Spikins's *GIS Models of Past Vegetation* [10, 89]. Spikin's method uses GIS to combine a series of base maps as a database. Each map describes different terrain conditions such as soil types (shallow soils, wet basic soils, calcareous soils, well drained soils, etc), a topographical map for defining altitudinal limits, and a coastline of glacio-hydro-isostatic model. Temperature changes were used for approximating the altitudinal limit of the tree line. A simple peat formation model was also introduced. The time sequence of each simulation is a 500 year interval with different base maps for each interval. Known presence of tree types taken from Birks [11] were used for defining the limits of the spread of each tree-type within the

intervals. A program designed within the GIS was used for determining the most probable dominant tree type in the landscape based on soil, climate preferences of each tree type along with information on the climate and presence of tree types for each phase. The simulation runs through two nested program 'loops' – the outer cycled through each date or period for which the model was being run, the inner circle through the mapping of each different possible woodland types allocating a dominant type for each unit. In [89], Spikins hinted on the use of a rule-based algorithm for selecting the most likely probable dominant woodland type for each area of layered information (Soils, topography, etc). The rule-based algorithm belonged to an *if-else-then* programming structure, demonstrating the use of a top-down approach.

In another study, Davis and Goetz [23] using GIS modelled the distribution of coast live oak. In the study digital maps of environmental variables such as geology, topography (elevation, slope angle, and slope aspect) and a calculated clear-sky solar radiation were weighted and overlaid for the simulation.

Fyfe [22] constructed and tested landscape simulations of vegetation patterns using GIS combined with the Pollen Landscape Calibration Model (POLLANDCAL) (details at [241-243]). The formula constructs the relationship between pollen dispersal, deposition and vegetation in combination with a Digital Elevation Model (DEM) reclassified for the simulation based on slope, altitude, and a combined altitude grids in the GIS. In the study, it is noted that the simplification of landscape and spatial scale (pixel size) affects the accuracy of the simulation. One of the many tradeoffs in the use of GIS-based models.

It was realised recently that the sensual or experiential approach in the study of prehistoric sites and landscapes is important for archaeological interpretations [90, 91]. Gearey and Chapman [91] attempted to tackle both the scientific and experiential aspect of an archaeological site by introducing a GIS-based *Digital Gardening* method. The main argument of the study based on Tilley's work [9] is that whilst a scientific approach, incorporating geological and ecological variables, is indispensable, it has become recognised that the subtleties of embodied space, essentially the experience of 'being in the world', is important in the interpretation of the spatial relationships between monuments, spaces between monuments and the routes that connect them. According to Gearey and Chapman, the potential synergy that might result from a closer integration between the scientific and the sensual/experiential often remained unrealised due to the lack in such studies. The current projects in Virtual Heritage are beginning to address these issues.

While the use of GIS-based models has penetrated the majority of research areas in vegetation pattern modelling, the field as a whole remained undeveloped in terms of visualisation and the accuracy of the model. The studies presented above have shown that as far as large-scale vegetation modelling and visualisation is concerned, the field can benefit from further developments in these areas:

- 1. Vegetation behaviour modelling related to different environmental conditions
- 2. Vegetation interaction modelling in small and large scale communities
- 3. Vegetation habitat and global and local environmental modelling
- 4. Interactive 3D and Virtual Environment for visualising the process of growth and developments of a landscape
- 5. Interactive Virtual Environment for exploration, investigation, and interpretation of a reconstructed archaeological landscape

### 2.6. Hardware Technologies for i3D Applications

According to Stone [124], during the closing decade of the 20<sup>th</sup> century, VR purists claimed that the users of today's real-time, multi-sensory computer environments would be exclusively wearing head-mounted displays, instrumented gloves and spatial tracking systems and that they would sit at Star Trek-like consoles within multi-wall projecting display facilities driven by graphics supercomputers. The claims did not happen. Instead, today's i3D users are reaping the benefits provided by a community of hardware manufacturers coupled with the entrepreneurs and programmers responsible for producing top of the charts computer games.

The development of computer graphics hardware began in the 1960s. Four decades later, market driven PC-based hardware technologies for multimedia demands and especially 3D computer games had pushed the capability limits beyond that expected by the computer graphics community. The era of expensive Silicon Graphics<sup>TM</sup> (SGI<sup>TM</sup>) workstations has diminished. Today the trend continues to advance for PC-based real-time graphics systems capable of rendering

unbelievably true-to-life gaming graphics. For example, a standard gaming machine today requires only an Intel 4.0GHz Pentium<sup>TM</sup> IV processor with HT technology with 1 Gigabyte of Random Access Memory (RAM) combined with a 256 Megabyte nVidia GEForce<sup>TM</sup> graphics card (See www.Dell.com website for a standard gaming machine).

A standard monitor or a flat screen display is generally sufficient for i3D displays. Display technologies for special needs are grouped into three categories. *Stereoscopic displays*, such as StereoGraphics' SynthaGram, an autostereoscopic projection monitor requiring no special eyewear. *Head Mounted Displays* (HMD), a wearable immersive display usually fitted with a 6 Degree of Freedom (DOF) or 3-DOF tracker. *CAVE*, a physical form of an immersive display. CAVEs are generally large, enclosed projection screens where users control the environment from inside the enclosure.

On the side of i3D devices, the standard keyboard and scroll-mouse seemed to be the satisfactory choice against a backdrop of many other expensive and high-tech but unpopular interactive gadgets. This is probably due to user-habits of using standard input devices that come with the PC, and definitely due to the lack of usability of 3D input devices. Zhai [244] studied user performance in relation to 3D input devices and concludes that the complexity of 6 DOF input is far from being solved and that none of the existing devices fulfils all aspects of usability requirements for 3D manipulation. Among the studies are mouse-based 6DOF devices, "Flying" Mice devices, desktop devices such as the Spaceball<sup>TM</sup>, SpaceMaster<sup>TM</sup>, the Space Mouse<sup>TM</sup>, and multi-DOF armatures.

### 2.7. Software Technologies for i3D Applications

Content generation tools for i3D creations are abundant these days. This section evaluates the more popularly used tools for the entire process of creating an interactive Virtual Environment.

## 2.7.1. 3D Modelling and Animation Packages

Two popularly used 3D modelling, texturing, animation, and effects applications are Autodesk's 3D Studio Max<sup>TM</sup>, currently version 9 and Autodesk's Maya<sup>TM</sup> (version 7), which was recently acquired by Autodesk's Media & Entertainment for film and TV industry [245].

Maya<sup>TM</sup> is a high-end 3D computer graphics and 3D modelling software package used in most films today. Maya<sup>TM</sup> has two packages, Maya<sup>TM</sup> Complete (the less powerful version) and Maya<sup>TM</sup> Unlimited. Another version, Maya<sup>TM</sup> Personal Learning Edition is free. Maya<sup>TM</sup>'s capability is its openness to third-party software which allows developers to write custom codes for any type of production. Another feature of Maya<sup>TM</sup> is its cross-platform scripting language called Maya<sup>TM</sup> Embedded Language (MEL) which can be used to customise its core functionality. The 3D tools allow modelling with polygons, NURBS, and Subdivision modelling. Maya<sup>TM</sup> is also able to simulate particle effects, fluid dynamics, cloth, fur, hair, physical effects, and inverse kinematics for character animation. It has a native *mental ray* rendering tool. It also integrates a 2D modelling tool into the 3D environment.

3D Studio Max<sup>TM</sup> is currently the most widely used 3D package available. It became a successor to 3D Studio versions 1.0-4.0 for DOS. It contains most tools available in Maya<sup>TM</sup> and is used by companies in the media and entertainment industry such as Industrial Light and Magic (ILM), Blizzard Entertainment, and Ubisoft.

Other 3D content generation tools are also available. These are NewTek's Lightwave 3D<sup>TM</sup>, Caligari's Truspace<sup>TM</sup>, and Rhino3D<sup>TM</sup>. Open source 3D content generation tools such as Blender3D<sup>TM</sup> are also becoming popular.

## 2.7.2. Texture Creation Tools

The most powerful tool for texture creation is Adobe's Photoshop<sup>TM</sup> CS, currently version 2.0. Photoshop<sup>TM</sup> is an industry standard tool and the market leader for commercial bitmap graphical editor. Most 3D texturing tutorials found on the WWW uses Photoshop<sup>TM</sup> with its host of plug-ins for effects generation. Alternatives are Corel's Photo Paint<sup>TM</sup> and the open source GIMP<sup>TM</sup> and Paint.NET<sup>TM</sup>.

## 2.7.3. 3D Landscape and Plant Creation Tools

By nature, 3D modelling packages are able to model landscapes and plants, although not as automated as proprietary landscape and plant creation tools. 3D Nature's World Construction Set <sup>TM</sup> (WCS<sup>TM</sup>) and Visual Nature Studio<sup>TM</sup> (VNS<sup>TM</sup>) are widely recognised as the best terrain visualisation software packages. It allows modelling, rendering, and animating natural and manmade environments with photorealistic quality. An import feature allows GIS and spatial data to be imported for rendering. It also has a ready-made collection of 3D plants and objects.

Animatek's World Builder<sup>TM</sup> (AWB<sup>TM</sup>) is a 3D landscape creation, animation and rendering tool. It renders very realistic natural scenes and is the only standalone 3D landscape tool that can work as a plug-in for 3D Studio MAX<sup>TM</sup> and Maya<sup>TM</sup>. It also has a ready-made collection of common 3D plants. The plant editor in AWB allows creation of new 3D plants and for modifying existing models. Users have the choice of detailed true 3D models, simplified plants and fast rendering 2.5D billboards. All plants can be animated quickly and easily with the Animation Wizard. The Variator tool for L-System based plants allows users to generate random variations from the original model for realistic clusters of trees.

SpeedTree Max<sup>TM</sup> is a plugin for 3D Studio Max<sup>TM</sup> for animation and visualisation of leaves and trees moving in wind. Bionatics natFX<sup>TM</sup> is an advanced procedural tree modelling plug-in for 3D Studio Max<sup>TM</sup>. The plug-in uses virtual seeds to initiate the growth of very accurate tree and plant specimens. natFX<sup>TM</sup> plants and trees are capable of simulating very exact detail in the plant growth of 3D models such as age, season, species and how they are affected by wind.

Greenworks' Xfrog<sup>TM</sup> 3.5 is a very good 3D graphics program, used for organic modelling and animation. Xfrog<sup>TM</sup> 4.0 integrates with Maya<sup>TM</sup>. The philosophy behind Xfrog<sup>TM</sup> is to offer various mathematical procedural components, to provide a way to simulate various types of

mathematical structures found in nature. For example - a Tree component, which simulates the way real trees branch. A Phiball component, which simulates distribution of the golden mean across the surface of a sphere, which is commonly found in Flower centres. Common uses include modelling and animating trees, flowers, bushes, Organic-Iterative Architecture, Abstract Organic Structures. Xfrog<sup>TM</sup> provides organic objects such as the branch object, phyllotaxis, hydra, curvature, variation, tropism objects which when combined, allow users to quickly build a wide variety of plants and organic objects. The growth factor of the objects is also based on the L-System and the golden proportion found in natural plant growth. All the objects can be animated by varying their parameters, such as number of branches, strength of attraction, gravity, and phototropism. With such techniques available, a convincing flower can be built and animated very easily, or a tree can be modelled and animated to grow. Xfrog<sup>TM</sup> easily exports to industry standard formats for 3D modelling packages.

### 2.7.4. Programming Languages

In order to create custom applications for modelling and simulation in research, programming languages are necessary. Many types of programming languages have been developed. The more popularly used languages are C, C++, Microsoft's C-sharp (C#) and Visual Basic (VB), and Sun Microsystem's Java. In recent years, The Object-Oriented Programming (OOP) model has replaced many Procedural languages. Except for the C language, the languages listed above are all OOP capable. OOP languages are easier to edit, debug, extended, and reused. It is also nearer to the way humans think and to the model of our physical world. For example, OOP languages are composed of properties and methods reflecting physical objects and organism in the real world. The properties or attributes of a pencil may be that it is red in colour, and 4 inches long. It has the "write" method and if it has an eraser attached at the end, it can also "erase". At present, the C and C++ programming languages are the industry standard for creating VR and i3D applications. C# is becoming more popular for VR and i3D with Microsoft's .NET framework.

# 2.7.5. 3D Application Programming Interfaces (API)

Programming language by itself is not sufficient for creating interactive Virtual Environments. There is the need for an interface that can communicate instructions to specific hardware. This interface is called Application Programming Interface (API). In the case of 2D or 3D rendering instructions, the target hardware is the graphics card. Both Microsoft's DirectX (currently version 9.0), and Open Graphics Library (OpenGL) are industry standard APIs. Both were designed with the same objective in that they can draw static and real-time 2D and 3D graphics. While DirectX works in the Win32 platform, OpenGL is a cross-platform API.

## 2.7.6. Games and Graphics Engines

A games or graphics engine is a core software component that supports real-time interactive graphics and game creation. Games engines are used in either a computer game or an interactive application for entertainment or simulation. The core of a games engine should at least include a 2D or 3D renderer, and may include a scene graph for object management, a physics engine, collision detection, navigation models, sound systems, animation, and some AI functionality. Games engines often provide scripting tools to allow programmers to control or change certain aspects of the game. Two types of games engine exist. A games engine that is bundled with a computer game allows a gamer to make changes to a game by accessing its core functionality. A mod (modification) is made by a gamer that can enhance a game by adding new levels, storyline, characters, and objects, or it could be created as an entirely new game. Computer games engines usually come with a visual editor called an Integrated Development Environment (IDE) for easing level editing and creation and for importing custom 3D models. Although most 3D games today allows modding, Epic Games' Unreal<sup>TM</sup> and Ubisoft's Farcry<sup>TM</sup> are two examples that comes with an IDE. Although Unreal<sup>TM</sup>'s editor is very popular and has been used in Virtual Heritage, evaluation in the research presented here showed that the newer Farcry<sup>TM</sup> Sandbox<sup>TM</sup> editor is superior in terms of usability.

Examples of games and graphics engines in the second category are Ogre3D<sup>TM</sup>, Delta3D<sup>TM</sup>, Genesis3D<sup>TM</sup>, and Irrlicht<sup>TM</sup> Engine, all open source-based engines. The examples given can also

be called graphics engines as they provide only a general real-time 3D rendering capability instead of the full functionality required by games. These types of engines are designed to make it intuitive for developers to produce 3D applications without the need to write programs from scratch via the low-level 3D APIs like DirectX and OpenGL. It abstracts the program core by providing a wrapper over the underlying system libraries of 3D APIs. For example, to program a walkthrough navigation in DirectX requires developing a software class library that receives parameters, manipulates world and camera matrices, detects collision, and computes frustum and occlusion culling, all mathematically intensive. The functionality provided by graphics engines already includes a pre-programmed camera class. Different navigation modes (flythrough, walkthrough, study) are usually part of the class. All that is required of a developer is to use the class simply by passing in required parameters. For example, in order to walk forward at a speed of 2 units towards a direction specified by the mouse, all that is necessary is a simple function call: Camera.Walk ( 2, Mouse.Direction ). The graphics engines listed are simply core libraries designed for use with a programming language and do not provide a visual editor such as the Unreal<sup>TM</sup> Editor and Farcry<sup>TM</sup> Sandbox<sup>TM</sup> Editor.

## 2.7.7. Data Description Techniques

Extensible Markup Language (XML) is a simple, very flexible text format derived from SGML (ISO 8879). Originally designed to meet the challenges of large-scale electronic publishing, XML is also playing an increasingly important role in the exchange of a wide variety of data on the Web and elsewhere [246]. XML is already becoming the preferred language for interfacing between databases and the Web, and it is becoming an important method for interchanging data between computers and computer applications [247]. XML is a flexible way to create "self-describing data" – and to share both the format and the data on the World Wide Web, intranets, and elsewhere [248].

On one level, XML is a protocol for containing and managing information. On another level, it's a family of technologies that can do everything from formatting documents to filtering data. And on the highest level, it's a philosophy for information handling that seeks maximum usefulness and flexibility for data by refining it to its purest and most structured form [248].

XML is better than standard database systems for data modelling as they are inexpensive in resource usage and can be used with existing Web protocols (such as HTTP and MIME) and mechanisms (such as URLs) without imposing any additional requirements. XML is formal and concise and also supports a wide variety of applications [247]. It is also a standard adopted by the World Wide Web Consortium (W3C) [249].

## 2.8. Optimisation Techniques

Simulating large landscapes with thousands of plants requires optimisation as computational resource is limited even with the most powerful supercomputer. As this project targets the PC by reason of its accessibility for general Virtual Heritage applications, optimisation techniques are mandatory. There are many optimisation algorithms for rendering efficiency. *View Frustum Culling, Occlusion Culling, Contribution Culling* and *Binary Space Partition* (BSP) are popular methods.

*View Frustum Culling* omits objects from being drawn if they are not within the view frustum volume, which are the six planes of a camera view point. The front and back of a clipping plane corresponds to the viewer's point and infinity. *Occlusion Culling* prevents objects from being added into the rendering process by determining which objects are hidden by other objects from a viewpoint. *Contribution Culling* prevents objects that are too far away to contribute to the scene from being rendered. BSP is a method for handling complex spatial scenes such as those used within a virtual building with polygon surfaces in all directions. The BSP algorithm recursively subdivides a space into convex sets by hyperplanes and represent them as a tree data structure. Other space partitioning structures are Quadtrees and Octrees.

While these techniques are efficient and have become a standard in games engines, they cannot contribute to the requirements of the modelling aspects of this research. In an outdoor 3D game, the vegetation is not 'alive'. Neither do they sense the environment and compete for survival. Therefore, when these plants are not within the viewable space, they are excluded from the computational process. In the real world however, the lifecycle of vegetation persists through time whether or not they are being observed. No algorithms exist for optimising this process and one must be developed, especially for real-time modelling and simulation.

### 2.9. Conclusion

In this chapter, specific areas related to the implementation of a 'living' environment in the context of Virtual Heritage have been discussed. A review of Virtual Heritage research related to landscape reconstruction and Virtual Environments inhabited by living entities found a little more than ten examples. The reason behind the lack of relevant studies may be due to the fact that agentbased or evolutionary simulation research in Virtual Heritage are relatively new topics (although more "classic" VR projects, involving fairly static "fly-through" environments, are reasonably commonplace). Aside from landscapes that are in existence today, the survey revealed no Virtual Heritage reconstructions related to submerged ancient landscapes. Using games engine technologies for reconstructing heritage sites has, however, become quite popular of recent years, as was witnessed during the review - many landscape reconstructions have, for example, employed the Unreal<sup>TM</sup> games engine as the run-time platform of choice. In Virtual Heritage, work has also been carried out on animating certain forms of living beings as inhabitants of Virtual Environments. An entity residing in a virtual world that is considered 'living' should at least possess some characteristic behaviour that allows it to respond to the environment as any natural organisms would, within certain parameters, defined, for example, by the context under study. It was found in the review that, typically, virtual avatars and (to a lesser extent) virtual "crowds" representing historical figures are popular topics for study.

There are a limited number of implementations of living entities in Virtual Heritage. In the field of Artificial Life however, a great body of research is based on the modelling and the synthesis of life. An overview of the field of Artificial Life, its principles, methods, and applications has been conducted. The review has laid the foundation for the present research in terms of the philosophy, concepts, and techniques required for "synthesising life in voltage and silicon", as described by Whitelaw [205]. Furthermore, a chronological review of alife-based vegetation modelling has revealed partiality and deficiencies in some of the approaches, particularly in respect of the fundamental principles required to synthesise the behaviours of plant species properly. It was discovered that no single system mentioned in the review addressed these issues – it was concluded, therefore, that they could not have been sufficiently accurate for plant synthesis. Furthermore, graphical rendering of most alife-generated examples typically result in very static representations (i.e. "snapshots" of the plant at a given time), whereas research into

Virtual Heritage regularly demands real-time, interactive media. The present research, then, seeks to address some of the issues that are partial and lacking, including:

- 1. Generic vegetation model capable of including all vegetation types
- 2. Individual plant life cycle seed, seedling, young, mature, and old
- 3. Generic plant life cycle growth, survival, competition, and reproduction
- 4. Vegetation forms (trees, shrubs, herbs, grass, etc)
- 5. Seasonal differences (evergreen, deciduous)
- 6. Competitions based on vegetation types canopy, density of leaves, height, and vegetation types
- 7. Competition for space and sunlight
- 8. Nutrient accessibility
- 9. Adaptability to ecological factors and resources (sunlight, temperature, carbon dioxide, altitude, soil, hydrology, and etc)
- 10. Ground Conditions soil acidity, soil depth, soil textures, ground slopes, and etc

It was also discovered that while the use of GIS-based models has penetrated the majority of research areas in vegetation pattern modelling, the field as a whole remained undeveloped in terms of visualisation and the accuracy. The review showed that as far as large-scale vegetation modelling and visualisation is concerned, the field can benefit from further developments in these areas, including:

- 1. Vegetation behaviour modelling related to different environmental conditions
- 2. Vegetation interaction modelling in small and large scale communities
- 3. Vegetation habitat and global and local environmental modelling
- 4. Interactive 3D and Virtual Environments for visualising the process of growth and developments of a landscape
- 5. Interactive Virtual Environments for exploration, investigation, and interpretation of a reconstructed archaeological landscape

This chapter also assessed the hardware and software technologies for creating i3D applications. The conclusion is that, despite a number of "false starts" in the 1990s, the VR/VE field (as it was known) is now ready for incorporating scientific models into visually rich

interactive Virtual Environments, with games and graphics engines technologies providing an exciting and highly usable platform from which meaningful experiments can be launched.

In summary, the main theme of this research is to evaluate the potentials of alife-based techniques for modelling the ecological environment and behaviours of vegetation, which until now have not been accomplished. The goal is to incorporate the research model and results into a real-time Virtual Environment for Virtual Heritage explorations and archaeological interpretations. With this in mind, and through the conduct of interactive modelling exercises and experimental observations, the rules inherent in the nature of vegetation ecology can, it is hypothesised, be found. By learning the principles of nature, that is, the use of simple rules to synthesise complex behaviours, the Virtual Heritage community can, perhaps, obtain a reasonably credible glimpse of what today's submerged Shotton river valley might have looked like many centuries ago.

# Chapter 3

# **Early Investigations: Interactive Virtual Environments**

#### 3.1. Introduction

The accumulated knowledge and perceptions of subject matter experts in archaeology in the periods before the flooding of the North Sea is a crucial factor for reconstructing the Shotton river valley in Mesolithic Europe. Knowing the landscape's time and place should provide us with an index to its climatic settings from palaeo-environmental reconstructions. Furthermore, techniques used in pollen analysis can be used to determine vegetation types, a source of information for indicating the faunas that thrived within the period. Archaeological findings and carbon dating of human remains, excavations of dwellings, and traces of food residues have also ascertained the fact that cultures existed during the Mesolithic times. This collation of information has in the past helped geologists and archaeologists in their perception and interpretation of past landscapes, and now, will help the Virtual Heritage reconstructions in this research.

This chapter provides an early technical investigation into the process required for reconstructing an ancient landscape. Beginning from section 3.2, the prehistoric settings, environments, cultures, and presence of vegetation types during the peak period of the Shotton River Valley are gathered. Section 3.3 covers the technical processes required for reconstructing a virtual terrain from seismic data sources. The section also investigates the application of computer graphics techniques and special effects for recreating cultural sites and artefacts related to the landscape. Section 3.4 evaluates three categories of VE for i3D explorations. The chapter is concluded with a discussion of the research in section 3.5.

## 3.2. Archaeological Perception of the Shotton River Valley

As early as 1913, the experienced geologist Clement Reid laid down his perception of the North Sea plain as a landscape which originally was available for human habitation [250]. In 1936, Clark's work on the Mesolithic Settlement of Northern Europe [251] provided evidence of dry land in the North Sea, based on archaeological findings and pollen records. In a later study, John Wymer [252] highlighted that the North Sea plain was both a land corridor and a place in which to live and provided an impression of a Mesolithic setting in a painting depicting a village probably around the years 8,500bp (Figure 6). In 1998, Coles [8] in the Doggerland project [253-255] reflected on the now-submerged North Sea landscape with human settlements before the ice-sheets retreated further and sea levels rose to the final separation of the British Peninsula from the mainland. Recent archaeological explorations have also discovered Mesolithic dwellings in the Northumberland and Dunbar regions of the British Isles [256, 257]. These ancient dwellings, together with the submerged Shotton River (Figure 7) - the focus of eager exploration desires of archaeologists, geologists, and the media [258, 259] certainly is not readily accessible for explorations. Even scientists such as Reid and Clark in their days, due to specific limitations in technology and the lack of computers, were able only to produce a speculative map of the landscape now submerged under the North Sea. However, the incremental powers of computing facilities and advances in 3D content generation tools have overcame the limitations. Advances in seismic technologies and 3D visualisation technologies have since made acquiring submerged datasets reasonably straightforward for accurate reconstructions. Throughout this project, the involvement of experts in landscape archaeology, geo-archaeology, and palaeo-environments from the University's IAA (see acknowledgements) on top of the author's literature review have led to a wealth of information, compiled as the introductory contents of this chapter.

Chapter 3. Early Investigations: Interactive Virtual Environments



Figure 6. John Wymer's impression of a Mesolithic village in the years around 8,500bp. (Source of Image: *Wymer, J.J., Mesolithic Britain. 1991, Princes Risborough: Shire Archaeology*)


Figure 7. Location of the Shotton River Valley in relation to the United Kingdom and the European Mainland (Holocene shorelines referencing Jelgersma [260], and Lambeck [261])

# 3.2.1. Geological Time Scale

The history of the earth is divided into four main divisions called periods consisting of Epochs. We dwell in the Quaternary, a continuation of the Tertiary interval. Some preferred the division of the Tertiary interval into two periods, the Neogene and Palaeogene. A diagram (Figure 8) is constructed based on studies in related literatures [262-267]. The Quaternary period is a major Geo-Chronological subdivision, which includes the Pleistocene (c. 1.8-2.45 million years ago before present) and Holocene (c. 10,000bp) epochs and marked by the appearance of species similar to modern humans and Homo sapiens. Basal deposits that overlie Pliocene deposits define

the base of the Quaternary. The Quaternary period was marked by repeated invasions of vast areas of mid-latitude North America and North Western Eurasia by ice sheets and is frequently referred to as the Great Ice Age [267].

Eon	Era	Period	Epoch	Age Ma
	Cenozoic	Quaternary	Holocene	0.01
			Pleistocene	1.64
		Neogene	Pliocene	5.2
			Miocene	23.3
		Palaeogene	Oligocene	35.4
			Eocene	56.5
			Palæocene	65.0
Si Ci	-2	Cretaceous		145.6
Phaneroz	Mesozo	Jurassic		208.0
		Triassic		245.0
	Palaeozoic	Permian		290.0
		Carboniferous		362.5
		Devonian		408.5
		Silurian		439.0
		Ordovician		510.0
		Cambrian		570.0
roterozoic				
L				2500
vchean				
<u>م</u>				4000

Figure 8. A Diagram of Geological Time Scale based on Harland *et al.* (1989). The age specified as *Ma* refers to *Million years ago* 

The Pleistocene (Ice Age c. 1.8 million to 10,000 years ago), is marked by an increasingly cold climate, by the appearance of the *Calabrian mollusca* and *Villafranchian* fauna with elephant, ox, and horse species, and by changes in foraminifera. The oldest form of man (Australopithecus) had evolved by the Early Pleistocene (c. 1.8 to 730,000 million years ago bp) and by the mid-Pleistocene (c. 730,000 – 127,000 million years ago bp) Homo sapiens evolved in Africa and Europe and spread to Asia and the Americas before the end of the Epoch. There were mass extinctions of large and small fauna during the Pleistocene. The Pleistocene is succeeded by the

Holocene, which is the present geological epoch. The Holocene began some 10,000bp (8,300bc) years ago. The Holocene epoch falls within the Quaternary period and is marked by rising temperatures throughout the world and the retreat of the ice sheets. During this epoch, agriculture became the common human subsistence practice and Homo sapiens diversified their tool technology, organised their habitat more efficiently, and adapted their way of life [267].

In archaeological terms, the cultures in existence during the Holocene are classed as Palaeolithic (Old Stone Age  $2.5 \sim 1.8$  million to 10,000 years ago), Mesolithic (Middle Stone Age 10,000bp to 8,600bp or 6,000bc), followed by the Neolithic (New Stone Age), Bronze Age, and so on [267]. The time scale used is based on European time periods as certain ages such as the Neolithic begins at widely differing dates in different regions of the World [266]. Figure 9 is a time scale relatively smaller in comparison overlooking the Holocene epoch. Associated climatic intervals are provided. The period where the Shotton River Valley flourished is in the Mesolithic, where flora and fauna thrived before the flooding of the North Sea.



Figure 9. Timescale showing the division of the Quaternary period. The period of study is in red

### 3.2.2. Mesolithic Cultures

Around 10,000 before the present day, the last Ice Age was drawing to its close. The population of Europe was expanding into land newly abandoned by the glaciers. For the first time, the population was consciously engaged in altering environments [263, 265]. This population consisted of hunter-gatherers [268, 269], also known as 'foragers', with no knowledge of agriculture or animal husbandry. This period is called the Mesolithic, a transitory period between the time when human survival depended entirely on the resources provided by the land and water,

with only the simplest tools and weapons. The Mesolithic economy was supported by the use of plant foods such as hazelnuts and acorns [270-273].

The Mesolithic or Middle Stone Age [10, 266, 267, 270, 273-275] began with the invention of geometric microliths, small stone blades, around 1 cm in length (see Figure 10 for a 3D reconstruction). The whole of Mesolithic culture is characterised by the presence of microlithic industries. The intervals between the Magdalenian and this shortened Mesolithic is then reclassified as 'Epipalaeolithic', which is generally used to describe any assemblages after the main Würm glaciations (the most recent period of the ice age) that have microlithic components [266]. This period of time is associated with fundamental socio-economic as well as technological changes. Some authorities [276] have regarded the term Mesolithic as synonymous with the particular type of hunting, fishing and gathering economy that evolved as a response to post-glacial environmental changes, such as afforestation. There is general agreement that the Mesolithic economy increasingly made use of plant foods. Aside from hazelnuts and acorns [271, 272, 277-280] the direct evidence for this remains relatively unsure. Some scholars also noted the domestication of the dog, the semi-sedentism, and the social developments reflected in the advent of 'cemeteries' in some regions [257, 258] and the increasing deposition of grave goods.



Figure 10. 3D reconstruction of Mesolithic microliths glued onto straight shafts to make arrows

The Mesolithic culture is divided into three periods [275]. The Upper Mesolithic - The transition to the Mesolithic is usually at 10,000bp, with some overlap of stone tool types into the later cultural period. The lithics of this culture are dominated by a range of points made on large (40-90mm long) blades and these have strong resemblance with some cultures in mainland Europe (e.g., Brommian and Ahrensburgian). This is not surprising since mainland Britain has not yet been separated from continental Europe. During the *Early Mesolithic*, the culture is characterised by the presence of microlithic industries, which are often not larger than 40mm in length and could often be smaller. At present, there has been no evidence yet to suggest anything other than the dominance of a food-collecting (i.e., pre-agriculture) economy until the very end of the Mesolithic period. The early phase also has larger implements reminiscent of the preceding culture. The early

phase is usually separated from the later by the presence of broad-bladed microliths. Examples of the early Mesolithic in England and Wales are dated between 9,700bp and 9,000bp. The culture is distributed throughout England and Wales with the possible exception of the uplands of Wales. Physical separation from the rest of Europe was complete by about 8,500bp during the *Later Mesolithic*. This however, does not indicate that all cultural developments in this phase are indigenous [274]. Smaller microliths with narrow blades and the appearance of more geometric shapes (including a small scalene triangle) are diagnostic of the later Mesolithic (8,800-9,000bp). However, separation from the early phase is not always complete: narrow-blade industries show up before the insulation from the continent. Equally, some geometric industries are accompanied by larger, non-geometric forms. This is especially so in South and east England and in Wales. Pure geometric assemblages are especially common on the uplands of northern England. In total, however, the later Mesolithic presence is to be detected from upland, lowland and coastal sites. It is noted that there is some culture continuity between early and later Mesolithic periods, as there often is between the Mesolithic and the succeeding Neolithic.

#### 3.2.3. Climate and Environments

The Mesolithic period saw the greatest amplitude of climatic change of all prehistoric periods except for the Palaeolithic. By 8,000bp, the disappearance of ice from Britain allowed a very rapid rise in the overall temperatures in these regions. Simmons, Dimbleby and Grigson [273] stated that "The story told by pollen analysis, macrofossil remains, oxygen isotope analyses of ocean-floor cores and the reconstruction of circulation patterns allows statements of a fair degree of confidence to be made about the climate of Britain at this time." Estimated air temperatures in the Lowland Zone and in the Highland Zone since 12,000bp were given (Figure 11).



Figure 11. Estimated average air temperatures (A) in the Lowland Zone and (B) in the Highland Zone since 12,000 bp. Lapse rates range between 5.6°C and 7.6°C per 1000m., selected by Taylor [281] as appropriate for 'Boreal and 'Atlantic' phases. 1. Winter 2. Year 3. Summer. Adapted from Simmons, Dimbleby and Grigson [273]

Summer temperatures were higher than the present average of 15.7°C [262]. Lamb *et al.* [282] suggested that summers, although hot, would be short and that the rest of the year would be colder than at present. A generally more anti-cyclonic climate would bring less windy conditions.

Godwin [283, 284] divided the scheme of pollen assemblage into zones in the Flandrian period which comprises zones IV to IX of climates beginning with Pre-Boreal to the present Sub-Atlantic climate (See Figure 9). The Flandrian can be dated by radiocarbon and ranges from 10,000bp to the present day [267]. An explanation of each climatic periods is given by Kipfer [267]:

*Pre-Boreal* – A division of Holocene chronology, which began about 10,000bp and ended about 9,500bp. The pre-boreal Climatic Interval preceded the Boreal Climatic Interval and was a time of increasing climatic moderation. Birch-pine forests and tundra were dominant. It is a subdivision of the Flandrian Interglacial and represents the start of the Flandrian. (*syn.* Pre-Boreal Climatic Interval)

*Boreal* – A climatic subdivision of the Holocene epoch, following the Pre-Boreal and preceding the Atlantic climatic intervals. Radiocarbon dating shows the period beginning about 9,500bp and ending about 7,500bp. The Boreal was supposed to be warm and dry. In Europe, the Early boreal was characterised by hazel pine forest assemblages and lowering sea levels. In the

Late Boreal, hazel - oak forest assemblages were dominant, but the seas were rising. In some areas, notably the North York moors, southern Pennines, and lowland heaths, Mesolithic people appeared to have been responsible for temporary clearances by fire and initiated the growth of moor and heath vegetation. (*syn*. Boreal Climatic Interval)

*Atlantic Period* – In Europe, a climatic optimum following the last Ice Age. This period was represented as a maximum of temperatures, and evidence suggests it was warmer than average for the interglacial. It seems to have begun about 6,000bc when the average temperature rose. Melting ice sheets ultimately submerged nearly half of Western Europe, creating bays and inlets along the Atlantic coast, which provided a new, rich ecosystem for human subsistence. The Atlantic period was followed by the Sub-boreal period. The Atlantic period, which succeeded the Boreal, was probably wetter and certainly somewhat warmer, and mixed forests of Oak, Elm, Common Lime (Linden), and Elder spread northward. Only in the late Atlantic period did the Beech and Hornbeam spread into western and central Europe from the southeast. (*syn.* Atlantic phase, Atlantic climatic period).

Sub-Boreal – One of the five postglacial climate and vegetation periods of northern Europe, occurring c. 3,000-1,500bc or, according to some, AD, based on pollen analysis. The Sub-Boreal, dated by radiocarbon methods, began c. 5,000bp and ended about 2,200bp. It is a division of Holocene chronology (10,000bp to present). The Sub-Boreal Climatic Interval followed the Atlantic and preceded the Sub-Atlantic Climatic interval. It was characterised by a cooler and moister climate than that of the preceding Atlantic period. It is a subdivision of the Flandrian, starting with the Elm Decline. Frequencies of tree pollen fall, and herbaceous pollen rises, representing man's invasion of the forest in the Neolithic and Bronze Ages. It is correlated with Pollen Zone VIII, and the climate was warm and dry. The Sub-Boreal forests were dominated by Oak and Ash and show the first evidence of extensive burning and clearance by humans. Domesticated animals and natural fauna were abundant. (syn. Sub-Boreal Climatic Period, sub-boreal).

*Sub-Atlantic* – Last of the five postglacial climate and vegetation periods of northern Europe, beginning c. 1,500bc (according to pollen analysis, although radiocarbon dates are c. 225bc). It is a division of Holocene Chronology (10,000bp to present). The Sub-Atlantic Interval followed the Sub-Boreal Climatic Interval and continues today. It is a subdivision of the Flandrian, thought to

be wet and cold, a trend started in the preceding Sub-Boreal period. There was a dominance of Beech forests, and the fauna were essentially modern. During the Iron Age, pollen analysis shows evidence of intensified forest clearance for mixed farming. Sea levels have been generally aggressive during this time interval, although North America is an exception.

The data for climate during the Mesolithic did not permit many inferences about regional differentiation of regime. For the uplands, however, Taylor [281] corrected the data of Lamb *et al.* [282] at an altitudinal lapse rate of 5.6-7.6°C per 1,000m. A table is given below by Taylor [281] of the estimated average air temperatures for 500m in the Highland Zone and in lowland England during the Mesolithic (Table 1). Table 2 is a modified *Blytt-Sernander* scheme of climatic periods given by Mangerud *et al.* [285].

Table 1. Estimated average air temperatures for the Highland Zones and Lowland England (indicated in °C). From J.A. Taylor [281]

	6,000bc	5,000bc	4,000bc	3,000bc	
Highland Zone (>500m)					
July-August	14.6	15.1	15.4	15.2	
Dec-Jan-Feb	1.9	3.7	3.9	3.7	
Lowland England					
July-August	17.0	17.3	17.3	17.0	
Dec-Jan-Feb	4.2	5.0	5.0	4.9	

Table 2. Modified Blytt-Sernander scheme of climatic periods, given by Mangerud *et al.*[285]. Approximate dates of stage boundaries are given in uncorrected radiocarbon years before 1950

Climatic Period	Years (before present)	Condition	
Younger Dryas	11,000 -10,000bp	Late Ice Age	
Pre-Boreal	10,000 - 9,000bp		
Boreal	9,000 - 8,000bp	ыу	
Atlantic	8,000 - 5,000bp	Warm and Wet	
Sub-Boreal	5,000 - 2,500bp	Warm and Dry	
Sub-Atlantic	2,500 - Present	Cool and Wet	

In environmental terms, the period of the Mesolithic covers two rather different epochs. The first was one of rapid environmental change, when the withdrawal of the ice from Europe and North America brought in its train of ameliorating climates, the replacement of open vegetation communities by forests with attendant changes in the fauna, and rises in sea-level. This phase can

be conveniently terminated at 7,500bp with the final insulation of Britain from the European mainland [273]. This research uses vegetation from the Pre-Boreal and Boreal, leaning more towards the former. A comparison of climates and seasonal temperatures can also be taken from Atkinson, Briffa, and Coope [286], and Briffa and Atkinson's [287] studies.

## 3.2.4. Evidence of Vegetation Types from Pollen Analysis

The most obvious source of evidence for past terrestrial vegetation is that from studies of pollen cores [10]. Palynology or Pollen Analysis [288, 289] is the study of vegetation history using the microfossils (pollen grain and spores). It can provide useful information about the conditions of an area in the past. Hyde & Williams [290] applied the term Palynology to the study of spores and pollen grains from embryo-producing plants. A Swedish geologist, Lennart von Post in 1916 [291] first introduced pollen analysis and the techniques to analyse pollens. Pollen analysis is an important aspect of past vegetation reconstruction. Pollen and spores that are accumulated over time reveals the record of past vegetation of an area and the changes of climate. They are produced in huge quantities, which are distributed widely from their source. Vegetation pollen grains and spores are extremely resistant to decay as the shell of a pollen grain wall is made of highly resistant material. It is known that pollen spores from 400 million years ago can even be found today.

In 1916, von Post in his lecture presented in a meeting of Scandinavian scientists sets forth the basic theory of pollen analysis and explained why pollen was the ideal tool for studying changes in past vegetation, and by inference, climate. Five observations were noted [238]:

- 1. Many plants produce great quantities of pollen or spores that are dispersed by wind currents.
- 2. Pollen and spores have very durable outer walls that can be preserved for millions of years.
- 3. His research had indicated that the unique morphological feature of each type of pollen and spore remains consistent within each species, yet each different species produces its own specific form.

- 4. Each pollen and spore-producing plant is restricted in its distribution by environmental conditions such as moisture, temperature, and soil type. As such, each species is most plentiful in areas that best meet the plant's optimal needs.
- 5. Most wind-dispersed pollen and spores rarely travel very far before falling to the earth's surface within a small radius (within 50 km) from their dispersed source. Thus, by counting a sufficient number of fossil pollen and spores recovered from each stratum in a deposit, one could reconstruct the types and abundance of plants represented by those fossil grains.

Pollen Analysis involves the isolation of pollen grains from successive levels in a sediment, using standard physical and chemical methods [237, 292], their identification and enumeration.

Pollen, an airborne sediment can be accumulated on any undisturbed surface. Sediments containing fossil pollen have been taken from peat bogs, lakebeds, alluvial deposits, ocean bottoms and ice cores [293]. Sediments that are 12m thick deposited in lakes created by glaciations 12,000 years ago can provide a very good source of study. By boring a hole in the sediment, a vertical sequence of sediments can be taken, each of which has been deposited at a particular time in sequence. Each of these samples can then be analysed for pollen grains and spore content. A Pollen diagram, the graphical expression of pollen analysis is constructed with consideration of sampling error. From this diagram, vegetation information can be obtained by looking at the differences in amount of pollens in a 1cm cubic area. If the pollen amount is little, the area could be tundra (moss). Large amounts of pollen in the analysis may indicate that the area could be a deciduous forest, where vegetation depends on pollen or spore reproduction. These studies gave researchers information regarding the distance of pollen travel, the direction of wind, the identification of vegetation in an area, lake sedimentation, the turn-over rate of the ecosystem, climates, and etc. [294].

The application of pollen analytical techniques to sites in the British Isles began in the 1920s when Erdtman [295] described analyses from 38 sites in north-west Scotland, the Outer Hebrides, and the Orkney and Shetland Islands. Subsequently, Erdtman extended this work to England, Wales, and Ireland [296]. Stimulated by the potentialities of pollen analysis, papers on the pollen content of sediments in south-west Lancashire [297], on the Pennines [298, 299] and north-east

England [300, 301] appeared. Presently, techniques are being refined for understanding pollen placements for more accurate reconstructions of past conditions of a target area of study [289].

#### 3.2.5. Mesolithic Vegetation of the Shotton River Valley

Until 8,500 years ago, Britain was part of mainland Europe and the vegetation of Europe reached into it [20]. During the period, different tree types colonised ancient Britain at different times. Presence of vegetation types during the Mesolithic will be identified based on studies in this section.

The study of submerged landscapes often depended on information of dry land areas adjacent to the site of study to enable the construction of predictive models for the submerged areas. For example, Chapman and Lillie [302] used the case of Holderness, East Yorkshire (UK) as a suitable landscape for analogous study of Doggerland during the earlier Holocene.

Pollen analysis has been used by archaeologists and geologists for acquiring evidence of past terrestrial vegetation. Although acquiring pollen core samples from the North Sea bed has not been carried out at present, vegetation types and soil conditions can be acquired from palynological investigations of the same latitude in nearby regions [10, 303, 304]. In particular, Tweddle [303] mentioned that during the earliest Holocene, the pollen records from all sites within central Holderness are broadly similar and a palynological investigation [303] into the vegetation histories of four small (<4 ha.) infilled kettle holes located within central Holderness have shed light on the Holocene environmental history of the area. Tweddle's study showed that major woodland types may have been broadly similar around the Shotton river valley district [304]: "Climatic amelioration facilitated the expansion of tree Birches soon after ca 10,200-10,000 bp, with Salix also increasing in frequency. Although mixed Betula-Salix woodland appears to have rapidly covered much of the area, the canopy was relatively open and damp grassland herbs (e.g. Filipendula and Ranunculus acris-type) and Ferns flourished within the understorey. The development of these vegetational communities led to a marked decrease in erosion. From ca 9,600-9,500 bp, Corylus Avellana (Hazel Nut) and Ulmus (Elm) began to expand locally, forming a denser (or more continuous) canopy and shading out many light demanding herbs; although a temporary reduction in Corylus avellana-type influx occurred at approximately 9,600 bp, probably in response to a period of climatic cooling. Hazel-Elm woodland containing low levels of Birch dominated the vegetation until the expansion of *Quercus*, dated as ca 9,150-8,930 bp. It is likely that the majority of the input from the genus reflects *Q. robur* (Pedunculate Oak), with the clay-based soils of Holderness favouring the taxon for much of the Early and Mid-Holocene. Dense *Quercus-Ulmus-Corylus* woodland dominated until the expansions of *Alnus glutinosa* and *Tilia*. In keeping with the behaviour of Alder throughout Britain, dates for the sustained expansion of the taxon are diachronous, varying between ca 7,800 bp and 7,000 bp. This variation probably arose as a result of local differences in ecological, perhaps soil conditions."

Bennett [12] has also contributed to the post-glacial pollen stratigraphies of two sequences of lake sediments (Hockham Mere and The Mere, Stow Bedon) which is a good source of Mesolithic vegetation types in the regions of the Shotton River Valley.

The presence of a variety of vegetation types around the North Sea has been identified in the preceding paragraphs. However, since the Mesolithic is a distant 10,000 years ago, the question of similarity between past and present vegetation preferences towards environmental conditions needs to be answered. Since traces of Mesolithic vegetation have diminished, modelling past vegetation types will have to be based on the preferences of their modern counterpart. According to Bennett [305], it is known that many ancient types of vegetation have no modern counterparts. One example is the early colonising Hazel, which probably existed as a tree rather than a shrub species. This shows that the environmental preferences of past woodland types may have been subtly different [10]. However, according to Prentice [306], although the behaviours of vegetation, particularly of woodland types, might have been different on differing competitive environments, the behaviour would not have been fundamentally different. Allen's [307] studies on the vegetation and land-use in the Stonehenge landscape in the Mesolithic could give insight into the preferences of these woodland types on features of the landscapes such as open areas, valleys, etc. These supporting studies have shown that it is relatively safe to use the preferences of modern plants as models for reconstructions.

The Oxford Dictionary [308] defined *vegetation* as plants collectively and categorised types of vegetation as follows. A *Plant* is defined as an organism capable of living wholly on inorganic substances and lacking power of locomotion. A *Tree* is a perennial plant with woody self-supporting main stem and usually unbranched for some distance from ground (perennial - lasting

through the year; (of plant) living several years). Next in line is *shrub*, woody plant smaller than tree and usually branching from near ground. *Herb* is a non-woody seed-bearing plant; plant with leaves, seeds, or flowers used for flavouring, medicine, etc. *Grass* is (any of several) plants with bladelike leaves eaten by ruminants; pasture land; grass-covered ground. *Moss* on the other hand is small flowerless plant growing in dense clusters in bogs and on trees, stones, etc.

The vegetation types that are likely to thrive around the regions of the Shotton River during the Mesolithic are in these categories:

Trees – Pine (*Pinus Sylvestris*), Birch (*Betula*), Ash (*Fraxinus excelsior*), Oak (*Quercus*), Lime (*Citrus aurantifolia*), Elm (*Ulmus*).

Shrubs – The Hazel species (*Corylus Avellana*) could also be a tree type during the Mesolithic period. Alder (*Alnus*) is likely to be part of a wetland or streamside community and thus more like a shrub than a forest tree [275]. Willow (*Salix*) is also part of a wetland or streamside community and grows near wetter areas.

Herbs – The herbs of open habitats of the Late Devensian stage became rarer and rarer. The glorious wild-flower meadowland of the Late Devensian and Pre-Boreal was eventually converted into a green monochrome wilderness of a very few species of trees stretching from shore to shore. Few species of the Pre-boreal open grasslands could survive in the woodland shade. Even a species with wider tolerances, Wood Sage (*Teucrium Scorodonia*), was affected. Open habitat plants become etiolated in the woodland shade. At the time of the maximum development of the wildwood the pollen of herbaceous plants reached a low of 10% of the total compared to today's landscape where non-tree pollen, including grass pollen, often exceeds 90%. They include Braken (*Pteridium esculentum Forst. F.*), Lesser Celandine (*Ranunculus ficaria*), Sedge (*Cyperaceae* family), Cat Tails (*Typha*), Sea Club Rush (*Bolboschoenus maritimus*), Dandelion (*Taraxacum*), Wild Parsnip (*Pastinaca sativa*), Burdock (*A. minus*), Thistle (*Onopordum acanthium*), Spear Thistle (*Cirsium Vulgare*), Silverweed (*Potentilla anserine*), Pignut (*Conopodium majus*), Hairy Hawkweed (*Hieracium longipilum*), Fat Hen (*Chenopodium album*), Bitter Cress (*Cardamine*), Ladies Smock (*Cardamine pratensis*), Stinging Nettle (*Urtica Dioica*), Yellow Mallow (*Pavonia praemorsa*), Yellow Archangel (*Lamiastrum galeobdolon*), Water Cress (*Rorippa nastutium*)

*aquaticum*), Marsh Samphire (*Salicornia europaea*), Rock Samphire (*Crithmum maritimum*), Cow Parsley (*Anthriscus sylvestris*), and Water Pepper (*Polygonum hydropiper L*.).

Grass – Open grassland are common throughout the Mesolithic landscape.

# 3.3. 3D Reconstructions: The Shotton River Valley and Mesolithic Dwellings

This section presents the first step in 3D reconstructions for a virtual representation of the Shotton river valley based on a multidisciplinary understanding of a range of details specific to its period, including geological formations, climatic settings, vegetations, and past cultures.

### 3.3.1. Seismic Data Conversion

The source of the study area is a dataset from seismic sources. The data, originally obtained from a PGS survey vessel "American Explorer" uses two 3090cu in Bolt Airguns as seismic sources and 6 Streamers (containing the Geophones) 3600 meters long. This gives an effective data resolution of 25 meters. The quality of spatial resolution provides adequate detail for three-dimensional topography. Figure 12 shows the time slice (at left) and analysis of the 3D voxel volumes of the seismic dataset in TGS Amira<sup>TM</sup>, an advanced platform for visualisation, data analysis, and geometry reconstruction.



Figure 12. Time slice and 3D voxel volumes of the seismic dataset showing features of the river valley



Figure 13. Basic visualisation of the contours and topography of the Shotton river valley in GIS

Initial investigation of the data revealed an interesting river valley to the north facing side of the study area thought to possess significant archaeological value. The data also revealed hints of ancient lakes and marshes. This prompted further studies in GIS and TGS Amira<sup>™</sup> for processing with the output as contours (Figure 13) and 3D voxel volume for analysis. Height fields were generated from the processed datasets and ported into 3D Studio Max<sup>™</sup> hosted on an Intel XEON 2.6GHz Dual Processor System with 1GB of RAM and an nVidia Quadro4 980 XGL 8X AGP Video Card. Due to the nature of the height fields, certain protruding faces and vertices of the polygon has to be edited to prevent a landscape with unnatural spikes. This gives an overall topography that is sufficiently accurate for study and for visualisation. The 3D terrain was also optimised to reduce polygon count and to prevent time and resource bottlenecks when vegetation or other artefacts were added later. Figure 14 shows the process.



Figure 14. Process of converting seismic datasets into polygon models

In order to explore and visualise the landscape in its natural form rather than from seismic 3D voxel volumes, it was decided to adopt 3D Studio Max<sup>™</sup> as the main content generation tool. Optimisation techniques were used to reduce the polygon count to a level manageable by a standard personal computer for real-time interactive modelling and renderings of the vegetation in the later part of the visual reconstruction process. Reducing polygon count in the initial stages of the terrain visualisation work not only conserves resources for reconstruction work but also does much to enable subsequent real-time visualisation via the Internet. Figure 15 depicts a high polygon model of the terrain for high resolution renderings and an optimised version for real-time applications.



Figure 15. A high resolution polygon model and its optimised version

Various techniques were investigated in simulating artificial nature such as the vast open grassland in the distance and grass representations in the foreground. Atmospheric effects (Figure 16) such as sky, water reflection, fog and fire were experimented with and added as part of the scene for realism and for aerial perspective effects. Figure 17 is a rendering of open grasslands in the Shotton river valley.



Figure 16. Computer generated effects



Figure 17. Initial rendering of the Shotton River Valley with CG effects applied

# 3.3.2. Vegetation Representation in 3D Space

There are various ways to represent vegetation in 3D space. Representation depends on the requirements of the target system. High resolution polygon models can be used in static production quality digital renderings and animations while low polygon models and billboards could be used in real-time i3D environments. Figure 18 is an illustration of various Level-of-Details (LOD) required by different systems. The two trees in the polygons section are detailed models from 3D Studio Max<sup>TM</sup>'s AEC Extended Foliage. Tree *a* is a high polygon model (19903 polygons) whereas tree *b* is a slightly optimised version with a lower polygon count (2324 polygons). The trunk and branches in both models are made of polygons and therefore solid. Each leaf is made of a 3D plane composed of two triangular faces. The plane is rendered on both sides. Polygon models are suitable for high-quality digital image and animation and are used for rendering movies in both games and the entertainment industry.



# 3D Vegetation Representation: Level-of-Details (LOD)

Figure 18. Different representation of 3D vegetation and the LOD required for targeted systems

Hybrids are suitable for real-time rendering. Hybrids are a mixture of polygons and planes. The trunk and large branches in a hybrid representation are usually polygon-based whereas the foliage and small branches are either hand drawn or an edited photo of a real plant. For the research presented here, three hybrid versions (a, b, c) were created in 3D Studio Max. In the experiments the *c* Hybrids version gave the best overall effect in real-time rendering. Different versions of it were created for various species.

Billboard models are suitable for representing vegetations that are too far away from a viewpoint to be considered for detailed rendering. Rendering engines that supports billboarding rotates the billboards (usually a single plane) so that the surface always faces the camera. This creates an illusion of a solid tree. The Virtual Reality Modelling Language (VRML) [309] is an example rendering engine that supports billboarding.

Billboard models in this research are used for sedges, herb and grass representations. Real-time visualisation experiments in this research showed that bending a triangle slightly gave a more 3D look during simulations.

### 3.3.3. Digital Reconstructions of Mesolithic Artefacts

Modelling the virtual Mesolithic dwellings and artefacts require delicate work in order to create a realistic representation, credible in the eyes of the archaeological community [256]. For Mesolithic houses, "construction" began by manipulating a cylinder primitive with 12 segments in 3D Studio Max<sup>TM</sup> into a variation of wooden poles and applying wood textures onto it. The poles were then scaled into variable lengths and positioned onto a pit with an earth mound 6 metres in diameter with an entrance. Straw patches were created and placed around the frames and doorway as covering. Two techniques were experimented with for the straw effects. The first technique scatters a polygon with 3 facets in random orientations to populate the cover of the hut with virtual straws.



Figure 19. 3D reconstruction of the Mesolithic house

The second technique applies straw textures and opacity mapping for protruding straws in the loose end of each patch. Figure 19 illustrates the process of reconstructing the virtual Mesolithic dwelling and Figure 20a and Figure 20b are two variations of the techniques.



Figure 20. Two techniques for recreating the straw covering and a completed site with Mesolithic dwellings and artefacts.

Although the first technique was more realistic, the second technique was used eventually, as the polygon count is much smaller. Finally, the completed Mesolithic dwelling was duplicated and placed appropriately around various features, such as the animated campfire with particle smoke and items of pottery scattered around the site (Figure 20c).

The 3D microliths were 'sculpted' by manipulating the vertices and polygons from a pyramid containing 3 width and depth segments, and 4 height segments. Both shaft and rope were created from a cylinder applied with the *noise* modifier. Tileable textures and a bump map, created in Photoshop were then applied to the objects as texture mappings. Figure 21 shows the process.



Figure 21. Creation of 3D microliths and shaft

Figure 22 shows an animal hide tanning rack. The inset shows how the hide is constructed from an extruded line, tesselated to create surfaces, with noise modifier applied and optimised. The rack is created with the same process as that for creating the frames of the Mesolithic houses.



Figure 22. Creation of 3D Hide Tanning Rack. Inset shows the process of creating the hide



Figure 23. Creation of 3D Fish with subdivision modelling

Figure 23 shows the subdivision modelling process of creating a fish for the fish drying rack. The fish is sculpted in low-polygon from a rectangle with 5 width and length segments, and 3 height segments. Sculpting is carried out on half the fish before mirroring the other half when it is completed. The low-polygon model is later subdivided to create a high-polygon version before applying and manipulating the texture with the texture *unwrap* modifier. The completed fish drying rack can be seen in Figure 24.

The log boat model is sculpted from a rectangle using the same method as that for the fish. The 3D log boat can be seen in Figure 25.



Figure 24. Creation of a fish drying rack



Figure 25. Creation of a virtual Mesolithic log boat and its smaller version

## 3.3.4. Early Visualisation of the Shotton River Valley

An early visualisation of the river valley was created with vegetation types manually positioned in appropriate places according to perceptions of geo-archaeologists at the IAA. This is mainly based on prior studies of preferences of vegetation types [14, 15, 20, 284, 307]. This method although subjective has provided an early perception of the landscape via the 'experiential' interpretation approach [90, 91] and have generated a great deal of popular interests in the media (e.g., [4, 259, 310-313]). The first output of this technical study is a sequence of 3D animation and high-resolution 3D renderings. In Figure 26 are two screenshots from an animation sequence featuring perceptions of the river valley as open grasslands. Figure 27 depicts another view in a foggy dawn and Figure 28 is a view from a small stream.



Figure 26. Two animation sequences featuring the river valley as open grasslands



Figure 27. A view overlooking the river valley, animation sequences are shown at the top



Figure 28. A view overlooking the extent of the river valley

The Mesolithic site were positioned in the 3D landscape based on models of the most probable locations of the dwellings – near the curve of a river valley for example – they were sited and blended into the surroundings with grass patches and trees and animated together with the Shotton River Landscape (Figure 29 to Figure 31).



Figure 29. Mesolithic dwellings on the river valley



Figure 30. Mesolithic dwellings on the river valley



Figure 31. Mesolithic dwellings on the river valley

The polygon count for the original high-quality reconstructions amounted to 444,408. The landscape polygon count reached 32,768 and each Mesolithic house comprised 36,549 polygons.

The high-performance model for real-time rendering, as described below, has a greatly reduced total amount of 26,194 polygons with the landscape at 4,718 polygons, with each house comprising 3,098 polygons.

### 3.4. Explorations in Virtual Environments and Interactive 3D

For real-time explorations, suites of VR interactive media were evaluated. The tests can be divided into four categories, seen in Table 3. The early Shockwave 3D was later decidedly discontinued as the other implementations are sufficient for early research in visualisation. A development in the walkthrough-only VR4Max<sup>TM</sup> was also abandoned.

Environments	Applications	Navigation Device	Tracker/Displays	
Web-based VR	VRML	Standard mouse	Standard Monitor	
	Shockwave™ 3D	Standard mouse		
PC-based i3D	VR4Max™	Magellan Spacemouse™	Standard Monitor	
Wearable	WorldViz's Vizard™	Standard mouse	3 degree-of-freedom (3-dof) Intersense Intertrax2™ angular (rotational) motion tracker and CyVisor™ Head- Mounted Display (HMD)	
Serious Gaming Environment	Crytech™ Engine	Standard mouse	Standard Monitor	

Table 3. Categories of VR Applications and Implementations

Figure 32 is an illustration summarising the first three categories of implementations. Terrains and scene objects in the first three categories are created in 3D Studio Max<sup>™</sup>. The high-quality renderings shown in previous sections and the real-time interactive environments described here required different computing resources, with the latter placing considerable demands on performance and visual/interactive quality. To meet these demands, the landscape and Mesolithic dwellings and artefacts use the optimised version. The PC-based i3D navigation tool uses polygon or hybrids-based vegetation. For web based VR and the wearable displays, billboards with genuine digital images of plants as texture mapping replaced polygon vegetation. Finally, the reconstructed 3D models and textures were customised for each of the test applications as each consisted of different features and limitations, in particularly, the different standards in the loading of 3D

models, the coordinates of texture mapping, digital images supported, navigation interfaces, and programming capabilities. For additional immersive VR implementations, WorldViz's Vizard<sup>TM</sup>, an OpenGL-based VR programmable development interface that communicates with common VR hardware was utilised.



Figure 32. Process of recreating the interactive 3D environment and its output for viewing on the web, desktop, and VR devices

### 3.4.1. Web-based VR

At the completion of the detailed and lengthy process of customisation, the Virtual Environments and 3D models in VRML and Shockwave<sup>TM</sup> 3D were published for viewing with Web browsers at a significant real-time rendering speed. Ambient and spatial sound effects of

running streams and chirping birds were added into the VRML environment. The spatial sound effects emit sounds in increasingly higher volume as the roaming user approaches the sound source and decreases with further distance. Exponential fog was added for aerial perspective effects. Figure 33 and Figure 34 are both respectively the VRML textured and the wireframe version. The skybox, a sphere representing the sky is seen in the wireframe version.

The VRML version is 10.9 megabytes in size. This includes all textures and 3D models. The VRML model was uploaded to a server and viewed via the Internet Explorer browser installed with ParallelGraphics' *Cortona*<sup>TM</sup> player (A VRML viewer plug-in). In full browser view at a resolution of 1280 x 1024, the real-time rendering when in motion, is at a speed of 24.5 Frames Per Second (fps). The speed drops to about 19fps when approaching the Mesolithic village, which has higher polygon count compared to groups of billboard trees while at 24.5fps. No significant lags were observed in both frame rates. Settings in the *Cortona*<sup>TM</sup> player are listed in Table 4:

Table 4. VRML Settings

Description	Settings	
General	Dither colour if possible	
Renderer	OpenGL renderer	
Anti-aliasing	Real-time	
Textures	Use texture mip-mapping	
Optimisation	Intel Pentium III or higher	
CPU-Load	0.8/1.0	



Figure 33. A Screenshot of the VRML textured version



Figure 34. A Screenshot of the VRML wireframe version

### 3.4.2. PC-Based VR

Both the high-polygon model and the optimised model performed very well (at close to 30fps) on the target dual-processor PC system with VR4MAX<sup>TM</sup>, a powerful VR runtime system that is capable of taking huge volumes of polygons for real-time walkthroughs. VR4MAX<sup>TM</sup> was used for a higher resolution representation and the Magellan SpaceMouse<sup>TM</sup> was used as a navigational device. Aside, from navigational walkthroughs, VR4MAX<sup>TM</sup> does not allow a programmable interface, therefore rendering it non-extensible for complex Virtual Environments.

#### 3.4.3. Wearable VR

For simple, semi-immersive explorations, the three Degree Of Freedom (3DOF) Intersense *Intertrax2* angular (rotational) motion tracker and *CyVisor*<sup>TM</sup> Head-Mounted Display (HMD) capable of 1.44 million pixels were used, together with *Vizard*<sup>TM</sup> on a Dell Precision M60 Mobile VR laptop. The mobile workstation is equipped with a 128MB nVidia Quadro<sup>TM</sup> FX Go1000 Graphics engine with 1GB of RAM and a Intel 1.7GHz Pentium<sup>TM</sup> M Processor. Customised 3D models built in 3D Studio Max<sup>TM</sup> were exported as VRML and the Wingware Python programming language was used to load as well as script parts of the immersive environment such as exponential fog, gravity, collision detection, ground based texture mapping, navigation with mouse, keyboard interaction, and 3D sound effects. Sound effects such as running streams and bird sounds were attached to transparent objects which were strategically positioned around river regions around clusters of trees across the landscape. At the initialisation of the system, user position is at centre of the Virtual Environment. Two Mesolithic villages were located at two probable Mesolithic settlement areas, at river mouths for example, for users to find and explore. Figure 35 depicts two scenes from the immersive environment with an inset of the author wearing the headset.



Figure 35. Two screenshots of the Vizard<sup>TM</sup> Immersive display. Inset shows the author interacting with the environment wearing a *CyVisor*<sup>TM</sup> HMD with *Intersense* 3DOF motion tracker

Vizard<sup>TM</sup> supports character animation compatible with 3D Studio Max<sup>TM</sup>'s biped. It also has a morph designer for creating facial expressions that could be useful in future research, together with the programmable Python language for inserting virtual Mesolithic men with AI behaviours into the scene.

## 3.4.4. Serious Gaming Environment

3D computer games of today are built on advanced real-time graphics engines. CryTek's CryEngine<sup>TM</sup> was chosen as the Serious Gaming application as it gave the best overall large outdoor scene. The process of implementation is slightly different from those in previous sections. Approximately 80% of the processes involved in previous implementations depended on 3D Studio Max<sup>TM</sup>. Since Farcry<sup>TM</sup> has a built-in real-time level editor (Sandbox<sup>TM</sup> Editor), which

makes creating large outdoor scenes and adding objects easier, the processes involved in using 3D Studio Max<sup>TM</sup> is minimised, although custom textures and 3D objects are still modelled using third-party software such as Autodesk's 3D Studio Max<sup>TM</sup> and Adobe Photoshop<sup>TM</sup>.



Figure 36. A scene in the Mesolithic Shotton river valley created using Farcry<sup>TM</sup> Sandbox<sup>TM</sup> Editor

Figure 36 is a 'plantless' CryEngine<sup>TM</sup> version of the Shotton River valley. Fog, clouds, and water reflections have been set to create the effect. The terrain is edited using the default terrain generator based on the seismic dataset with three textures mapped according to elevation and slope. The clay texture is mapped near the river banks while rocky surfaces are portrayed on certain slope angles. The overall landscape uses an open grassland texture.


Figure 37. A scene in the Mesolithic Shotton river valley created using Farcry<sup>TM</sup> Sandbox<sup>TM</sup> Editor

Figure 37 is a scene created in Sandbox<sup>™</sup> Editor. For a real-time rendering engine, the quality is excellent. In the scene, a 'windy' effect is created by controlling the swaying effects of trees and undergrowths. Bird flocks are added and controlled using the inbuilt Boids system which provided simple settings such as the number of birds, bird size, bird models, and simple AI for bird behaviours. Other 'living' entities are the wild boars (Figure 38) and fire flies (enlarged in inset). The characteristic of wild boars uses the 'pig' AI behaviour customised by settings such as hostility, attack range, aggression, etc. Other Mesolithic animals can also be included but will need custom modelling, character rigging and animation, and scripting. The AI can be scripted using the LUA script for better control of behaviours.



Figure 38. A scene with living entities and particle systems created using Farcry<sup>TM</sup> Sandbox<sup>TM</sup> Editor

In the scene are also 3D objects and a camp fire using particle effects. The fish drying rack, the hide tanning rack, and the log boat have been imported as larger scene objects (Figure 39). Some of these objects are applied with the inbuilt physics rigid-body settings. In particular, the water density of the log boat could be set so that in future implementations, the Mesolithic human could push it into the water for a ride. Figure 40 is a closer view of the fish drying rack.



Figure 39. A scene with Mesolithic artefacts created using Farcry<sup>TM</sup> Sandbox<sup>TM</sup> Editor



Figure 40. A scene with Mesolithic artefacts created using Farcry<sup>TM</sup> Sandbox<sup>TM</sup> Editor

Figure 41 is a setup of the Mesolithic village without vegetation. Plants will be added when the scientific model of vegetation is developed and applied in succeeding chapters. The evaluation has shown that *Ubisoft*'s *CryEngine*<sup>TM</sup> could become a potentially useful tool for extending research into the next phase for both modelling and visualisation when men and animals are needed as part of the system for modelling their cultural routines, food tendencies, settlement preferences, and travel patterns in the Mesolithic Shotton river valley.



Figure 41. A Farcry<sup>™</sup> in-game level showing the Mesolithic scene created using Sandbox Editor

## 3.5. Conclusion

The Mesolithic period saw the post-glacial amelioration of climate and an increasing abundance of migrating flora and fauna. The Shotton river valley is one such area benefiting from the changing climate. Early perceptions of archaeologists have shown that during the years before 7,000bp has once been a habitable land bridge where Mesolithic cultures survived before the flooding of the North Sea. The discovery of the river valley has further strengthened this perception. Literature regarding its time and place is abundant and the knowledge have become a crucial factor for its virtual recovery.

Reconstructing the virtual Shotton river valley began by adopting various industry standard software for investigating and converting seismic datasets into formats suitable for i3D systems. During the process, CG techniques have been applied to create a scene with natural effects. The best representation of vegetation for different 3D creations has been evaluated. Furthermore, digital Mesolithic houses and artefacts were recreated using best practices in CG for both static and real-time rendering. Finally, the virtual reconstructions were customised and ported onto various i3D and VEs for evaluating the interactive capabilities of these systems for scientific implementations later in this project, and for the future.

Much of the groundwork for a full scale Virtual Heritage exploration has been laid. The methods for vegetation placements on the landscape are somewhat subjective and are only sufficient for an early 'experiential' investigation. A look in related research in Chapter 2 revealed limitations in existing models of vegetation for determining distribution patterns in large landscapes. A better scientific model must be researched and developed in order to 'clothe' the landscape. The next three chapters of this thesis investigate, from different angles, the requirements for modelling vegetation with Artificial Life.