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Evolutionary Computation for Digital Artefact Design

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Evolutionary Computation for Digital Artefact Design

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Award Sought: Master of Science

Author’s Declaration

I hereby declare that:

1. This thesis is entirely my own work except where otherwise acknowledged or referenced.
2. This thesis has not been submitted for an award at any other institution.

Author’s signature: ____

Supervisor’s signature: ____

Abstract

This thesis presents novel systems for the automatic and semi-automatic design of digital artefacts. Currently, users wanting to create digital models, such as three-dimensional (3D) digital landscapes and website colour schemes, need to possess significant expertise, as the tools involved demand a high level of knowledge and skill. By developing an intuitive algorithmic process, founded on evolutionary computation (EC), this research enables non-specialist human designers to create digital assets more efficiently. This is achieved by replacing design activities that require significant manual input with algorithmic functions, thereby greatly improving the efficiency and accessibility of the practices involved.

This research places an initial focus on the generation of 3D landscapes, but the latter aspect concentrates on the identification of text and background colour combinations more amenable to the reading process, particularly for readers with vision impairments. Choosing an ideal combination of colours requires knowledge of the cognitive and psychological procedures involved. Designers need to be aware of colour contrast ratios, brightness, and variations, which would require a series of aesthetic measurements if they are to be manually tested. In an effort to provide a colour design facility, this research offers algorithms that can generate colour schemes, based on the aforementioned principles, which can be used to derive an optimum scheme for a website.

This research demonstrates a novel interactive genetic algorithm (IGA), coupled with the use of computational aesthetics, suitable for use in the evolution of terrain generation and digital landscape design. It also provides a tool for automatically creating EC-driven colour palettes for web design via evolutionary searches.

Experimental trials use the EC framework developed from this research using both IGA technique and the computational aesthetic measures. Results indicate that the end-users can build any target digital landscape design with less inputs and more comfort, and if required can also automate the whole process to evolve aesthetically pleasing landscape designs. The results obtained for designing colour schemes for website design have proven that end-users can quickly develop a colour scheme, without the need for fine-tuning of colour combinations. Results can compete in quality the colour schemes that are designed by the professional website developers.

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1 Introduction

The primary motivation of this research is to provide an intuitive means of constructing visual artefacts or graphical objects for video-games [1], as well as movies and social networks; all of which rely on vast and multifaceted virtual worlds [2]. A number of software tools and applications exist that can assist designers in the creation of such artefacts, but the use of these tools require a significant amount of time for manual input. Furthermore, users of such tools often require extensive training and practice before they are in a position to achieve the desired output [3]. In an effort to generate digital artefacts in a manner that is accessible to a wider user base, there is a need to remove this high level of dependency on user manipulation. Thus, this research focuses on procedural evolutionary techniques, where a computer generates digital artefacts by allowing users to direct an algorithm towards desired output, without requiring any specialist expertise. In an attempt to create such a technique, Auto Terrain Generation System (ATGS) was developed, based on novel evolutionary algorithms, the purpose of which is to allow non-specialist users to easily generate specific terrains in Terragen [4], a 3D landscape graphics engine, without having to master the vast number of fractal landscape settings offered by the platform. Terragen is a photorealistic scenery rendering software, developed by Planetside.

ATGS lays on the principles of genetic algorithms (GA) and IGA as suggested by Takagi [5]. GAs are global search heuristics used in a wide number of domains to find precise or approximate solutions to a range of optimization and search problems. GAs solve problems via an evolutionary search on a population of randomly generated individuals over a number of generations, whereby successive generations of individuals are selected via a fitness evaluation. The fitness evaluation is a key aspect of the search heuristic and is commonly based on an objective measure within the domain of interest. IGA is an extension to GA, where the fitness evaluation is done by the user.

When using this approach, the user gives the fitness score via selection of the “best fit” samples in each generation. In a similar way, ATGS users are required to rate aesthetically pleasing landscape designs from a set of initially generated designs.

They are presented with a set of 16 scenes that have been generated in Terragen by ATGS, and users are tasked with choosing the three scenes that they deem to be the most aesthetically pleasing. After the selection of best three scenes by the user, the system identifies which parameters a user is attracted to, and updates those values through evolutionary search in the next set of generation scenes. Each time the user completes a fitness evaluation by rating and selecting their preferred landscapes, a new set of generations is presented with the landscapes that are closer to the user target. This process iterates until the termination criterion is reached, i.e. when user achieves a landscape design that they are satisfied with.

The ATGS process, based on IGA techniques, is divided into five primary phases:

Phase 1: Initialization

A virtual landscape is defined by more than 800 floating points of fractal parameters. By altering these values, variations in the visual appearance can be seen in the final rendered output.

For example, a daytime scene can be changed into a night scene by changing the sun elevation parameter value from a 90 to 0 degree angle. Based on this logic, the initialization is carried out by inserting predefined parameter values that are generated randomly and the corresponding initial population, sixteen landscapes of phenotypes is presented to the user in the form of images.

Phase 2: Interactive Fitness Evaluation

At this stage, fitness evaluation is carried out by the user's selection of their three preferred landscapes out of sixteen, which they consider to be the best current representation of their aesthetic goals.

Phase 3: Selection Process

GAs select each parent for reproduction by using a probabilistic ranked selection process, known as the the Roulette Wheel Selection (RWS) [6]. Selection is biased towards those landscape definitions that are evaluated as having high aesthetic values by the user.

Phase 4: Crossover and Mutation Operation

In this phase, the reproduction process is applied on the selected terrains to produce a new population by using crossover and mutation operators. Crossover is applied between parent terrains to recombine their genetic information to form new offspring. Whereas, mutation operator is used to alter genetic information transferred from a parent to an offspring.

Phase 5: New generation

After performing the genetic processes, a new set of sixteen images is generated by rendering the numerical representation of the new landscape designs. After rendering them through the graphics engine, sixteen landscape designs are generated and sent to the Graphical User Interface (GUI) for further evaluation. The whole process is repeated until the termination point, i.e. where a user is satisfied and stops the process.

1.1 Aesthetic Measures for Terrain Generation

Considering the number of selections that need to be made, and the processing time required, users tend to grow tired of the process as it cycles through its iterations. User fatigue is recognized as a common problem within the field of IGA [7].

To counteract this, the system’s capabilities in relation to its use of computational aesthetic measures were extended, so as to entirely replace the user with a fully-automated process. Using computational aesthetic measures, users are able to specify basic parameters such as the target number of generations, so as to arrive at a finished product, having offered a significantly lower amount of feedback. This process is facilitated using techniques based on Information Theory [8], as well as a Global Contrast Factor (GCF) [9].

There are multiple additional approaches that could have been used such as Benford’s Law [10], Ross & Ralph (bell curve)[11], but only two aesthetic measures were chosen as initial investigation showed that evolutionary algorithms can evolve landscape designs through the use of just these aesthetic measures.

Information Theory is one of the most commonly used aesthetic measures in image processing by many researchers Unemi [12], Rigau et al. [13], den Heijer [14]. It identifies uniform patterns/colour patches in an image and calculates its informational data. The more it finds uniform patterns in an image indicates the less information it is holding and vice versa.

In practice the idea of Kolmogorov complexity is applied to measure the algorithmic entropy, which is used to measure randomness in a data. Based on this theory, Machado[15], Rigau and Heijer successfully implemented Information Theory as an aesthetic measure by using data compression to read information and rank them based on their aesthetic merits. The same technique has been used in this research to calculate the information contained in landscape designs and rank them accordingly.

The second aesthetic measure used in this research is GCF [16], which calculates the difference between pixel luminosity for an image. The value that is obtained by using GCF is used as a fitness score to identify whether the landscapes possess higher or lower contrast levels within a set of generated landscapes and ranks them accordingly.

Based on these two aesthetic fitness scores, Information Theory and GCF, a set of three best landscape designs are automatically identified by the EC framework. The evolutionary process continues with this strategy until the termination point is reached.

The utility of this approach is then evaluated with human users to see if such measures tend to generate more aesthetically pleasing images.

1.2 Colour Co-ordination for Web Design

Using the same technique and EC framework, a solution to the aforementioned web design issue has also been developed. Moving beyond simple black and white colour schemes requires the expert consideration of a vast search space of colour combinations, with each graphical element providing 16 million colour choices. For example, if n distinct elements in a web page are considered at the same time, the search space becomes $(1.6 * 10^7)^n$. Using the aesthetic measures, pleasing colours with proper contrast ratios between text and background colours are identified, thus automating the process (of producing agreeable colour schemes suited to readability).

At present designers are using manual tools [17] [18] while creating templates for Web design. A template's characteristics generally include a pre-defined user interface that incorporates a colour palette, theme, default images, font style, pre-defined navigation sub-system, and so on. The inter-relationships between the background image colours with foreground colours for text, links, buttons, etc., dictates the overall readability and look of a website. If the user wishes to customize the colour palette themselves, they may run into difficulties in identifying the right colour combinations based on the primary colours that have already been applied to the website's design. Using tools for finding suitable colour combinations still requires user effort, as each colour must be evaluated until the right combinations are found.

It is also required that designers manually maintain colour contrast levels for users who are vision impaired. Without maintaining the proper contrast level between colours, it may still be easy for the majority of users to distinguish the text from its background, but it will be difficult for users who suffer any such impairments.

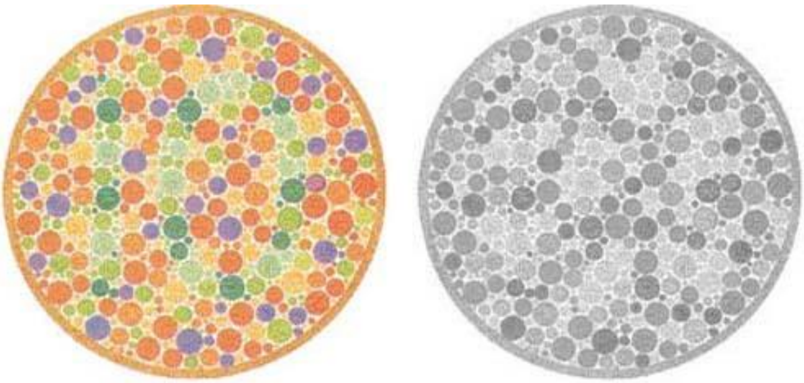


Figure 1. Colour combination test between normal (left) and impaired (right) vision. The test is to find the number 10 hidden in the image.

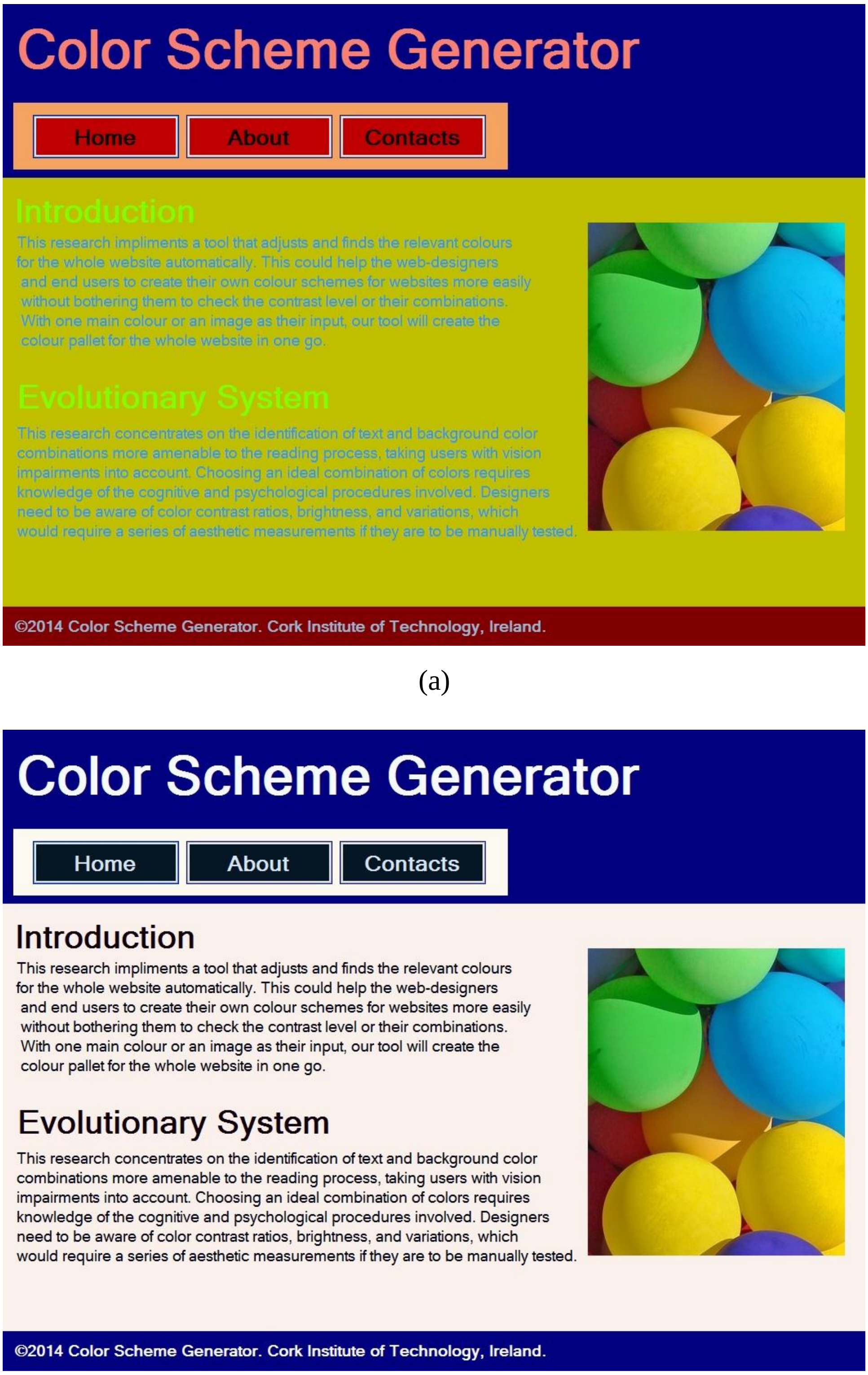
1.2.1 Aesthetic Measures for Web Design

The algorithms used to test and find the most aesthetically pleasing colour combinations are, Colour Contrast Ratio (CCR), Colour Brightness (CB), and Colour Difference (CD) [19]. During the fitness evaluation, the GA decides the better colour combinations in each generation, and continues the whole evolutionary process automatically until the right combination is found. According to the World Wide Web Consortium (W3C) recommendation, it is necessary to maintain adequate contrast levels between text and background colours so as to make content accessible to vision impaired readers. Based on their guidelines [20] [21], an algorithmic CCR is derived for calculating the required contrast levels between any two colours. Hence, CCR is used as an aesthetic measure in EC to maintain sufficient contrast ratio levels in colour combinations, from generation to generation in order to ensure the generated schemes are accessible for all users.

Brightness-adjustment is necessary when two colours are combined. If this is not conducted properly, and their properties are increased or decreased in tandem, then the colours will dissolve into each other, degrading the page’s readability. To calculate and adjust brightness at the right levels, based on W3C standards [22], the CB algorithm is used to detect brightness levels between any two colours. Hence, CB is used as an aesthetic measure in EC for automatically adjusting the brightness levels during the evolution process.

Any difference in colour between any two colours can also affect readability. For example, imagine reading red text on a reddish-pink background. To find the difference in colours, a W3C [22] derived algorithm, CD, is used to detect difference based on WCAG limitations. CD is used in EC to filter unwanted colour differences during the evolution process.

Utilizing these aesthetic measures, this research offers a novel formula that evaluates final fitness tests between any two colours. Initial testing demonstrates credible results, as the system accurately detects the remaining colours of a website when the main colour of a website is given as an input. Figure 2 shows the difference between a randomly generated colour scheme with a system that generated colour scheme, when “*Navy blue”* colour is given as an input.



Color Scheme Generator

Introduction

This research impliments a tool that adjusts and finds the relevant colours for the whole website automatically. This could help the web-designers and end users to create their own colour schemes for websites more easily without bothering them to check the contrast level or their combinations. With one main colour or an image as their input, our tool will create the colour pallet for the whole website in one go.

Evolutionary System

This research concentrates on the identification of text and background color combinations more amenable to the reading process, taking users with vision impairments into account. Choosing an ideal combination of colors requires knowledge of the cognitive and psychological procedures involved. Designers need to be aware of color contrast ratios, brightness, and variations, which would require a series of aesthetic measurements if they are to be manually tested.

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(a)

Color Scheme Generator

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(b)

Figure 2. A website colour scheme comparison between (a) randomly generated colours and (b) system generated colours by using EC.

1.3 Uses and Collaboration

This thesis offers a number of original contributions to the field. To further test and investigate this project's application of evolutionary theory for terrain generation, art, and web design, an in-house evolutionary computational framework was developed using .NET and C#. This project has been involved with a number of collaborative studies with scholars from the Digital Arts & Humanities cohort at University College Cork. The latter focuses on how people react to visual images that have been generated using algorithmic processes.

The system has been selected by Enterprise Ireland for funding in its Commercialisation Fund feasibility funding, Feasibility Support Grant Ref. No. CF 2014 0078Y.

1.4 Publications

The contribution that this research makes to the field is reflected in the number of publications that it has secured; at prestigious international conferences and in highly-regarded peer-reviewed academic journals.

Conference Papers

"Auto Terrain Generation System" – This paper introduces the Auto Terrain Generation System and demonstrates how IGA are used to enable non-specialist users to rapidly generate three-dimensional terrains [23].

"The use of aesthetic measure in the evolution of fractal landscape designs" - This paper uses aesthetic measures as opposed to Interactive Genetic Algorithms in an effort to reduce the user fatigue associated with the latter process. An aesthetic measure, based on information theory, which determines the fitness of artefact, is defined. Results showing that this approach produces artefacts that are aesthetically pleasing are also presented [24].

"The use of GCF aesthetic measure in the evolution of landscape design" – In this paper, Global Contrast Factor and information theory are combined to make a novel aesthetic measure, the purpose of which was to generate landscape designs that were increasingly aesthetically pleasing. Two types of experiments were conducted using GCF that facilitated fluid evaluation of computationally intensive fitness evaluation, with preliminary results reported [25].

“Computational aesthetic measure for evolutionary computation based Web design” (Best Paper Award at the Collaborative European Research Conference, 2014) - Three aesthetic measures were used in this paper to derive the most appropriate colour schemes for websites, taking into account readability factors [26].

1.5 Outline

The remainder of the thesis is organized as follows.

Chapter 2 will characterize the existing digital design approaches in the fields of terrain and colour scheme generation. A brief introduction of GA methods is presented at the beginning. In Chapter 3, the use of GAs methods in the evolutionary process for designing the EC framework is outlined. The implementation process of using a universal framework for two different problems to find an optimised solution, with various architectural designs, is provided in detail. The concepts of generating content for terrain landscape designs and colour scheme generation techniques for website designs, are also explained. Chapter 4 describes the setup of the experiments carried out for testing the capabilities of the EC framework to find optimized solutions in both terrain and colour scheme generation. The results of IGA and Aesthetic measures differentiation are deliberated by showing their individual outcomes. Chapter 5 gives an outline of the final outputs of this research, the proposed improvements that can be carried out, and the future scope of this work.

2 Literature Review

This chapter gives an overview of existing applications and methods for generating terrains and colour schemes. A brief introduction of GA methods, with examples, is explained in the first part. In the second part, background information on existing terrain generation applications and techniques for automatic content generation process are detailed, together with their drawbacks. A review of the existing attempted research methods to automate the process is also outlined. The third part explains the means by which colours are represented in a computational environment and describes a number of colour combination techniques. Finally, existing applications and tools, which help a user to create colour schemes, are reviewed together with their drawbacks.

2.1 Simple Genetic Algorithm

According to John Holland, GA solves complex problems in a manner that is not entirely comprehended, even by their creators [27]. They are inspired from Darwin's theory, *The Origin of Species* [28], which explains how organisms evolved in the natural world through natural selection and reproduction. Organisms are 'selected' by nature via the "survival of the fittest" process, and reproduce offspring that propagate their chromosomes through succeeding generations. In a similar fashion, GAs selects the fittest individuals through a fitness evaluation phase, reproducing the next generation until the solution to a particular problem, or a termination criteria, is reached. The evaluation of fitness is a key aspect of the search heuristic, and is commonly based on an objective measure within the domain of interest.

GA and Genetic Programming (GP) are global search heuristics used in a wide number of domains to find solutions to a range of optimization and search problems. IGA is an extension to GA, where the fitness evaluation is done interactively by the user. When using this approach, the user gives the fitness score via selection of the "best fit" samples in each generation. Methods from Holland's simple genetic algorithm (SGA), such as encoding methods, initialization, fitness function, selection, crossover, mutation and new generation cycle are explained to give a brief introduction to GAs.

In this research, initially SGA methods are applied to evolve terrain/landscape designs in order to test both the IGA and the aesthetic measured fitness based techniques. Modified-

SGA methods are gradually implemented into the website colour scheme evolutionary process with the aim of decreasing the time finding the solutions. Modified-SGA methods used in this research are: initializing population with “best fit” individuals by using aesthetic measures; a multi-point crossover technique; and an increase in the probability of the mutation rate. They are further described in Chapter 4, Design and Implementation with examples.

Algorithm1: Simple Genetic Algorithm structure

```
public class doGA
{
    initializePopulation();
    findSolution();
    public void findSolution()
    {
        repeat
        {
            fitnessTest();
            selectionProcess();
            encodeParameterValues();
            doCrossover();
            doMutation();
            decodeParameterValues();
            nextPopulation();
        } until(terminationCriterionReached == true);
    }
}
```

2.1.1 Encoding method

Real-valued continuous variables are commonly used in most of the optimization problems [29]. Before the GA process begins, each variable is normalized into a specified range and is then converted into fixed number of binary bits to form a binary string. For example, if the continuous variable value, water level, is defined as being in a range from -800 to 800, then it is brought into the -128 to 128 ranges, and then converted into 8-bit binary format to represent it in a binary string.

2.1.2 Initialize population

Initialization is the process of selecting a fixed number of individuals to form a population for finding the potential solution, based on the phenomenon “survival of the fittest”, for any given search-based problems. In a typical SGA method, the population size lies in between 30 to 200 [29] and the features of each individual are randomly generated. The exact size of the population is dependent on the designer and the problem type, as increasing the population size can increase diversity within the group selected but will take longer time to get the suitable features into the search space. But, when population size is decreased this could lead to less diversity over the initial population group, which may cause less effective results at the end of the GA process [29].

In this research, both the traditional (randomized method) and Garis [30] way of initialization are followed. Garis selected the fitter individuals, instead of randomizing features in individuals, by performing a fitness test at the initial stage, aiming to decrease the time taken by the GAs to find the solution.

2.1.3 Fitness test

After the initialization process, the fitness function phase is executed to evaluate each individual present in the population. Only those individuals that possess high fitness are likely to be selected and reproduced in the next phase, whereas the individuals with the least fitness are left behind. The function to evaluate the individual fitness score is either set by the algorithm designer (SGA) or decided by the user (IGA).

In this research, both IGAs and aesthetic measures are used to form fitness functions while evaluating both landscapes and website colour schemes. Aesthetic measures are implemented mainly to improve SGA fitness accuracy, as it is not easy to define a fitness function without user intervention [31] and to replace user involvement in IGA technique to tackle user fatigue that is caused while manually evaluating various features on each individual in the entire population.

2.1.4 Selection process

The fitness test is performed on each individual; the selection phase executes to select individuals for the reproduction to produce offspring. In SGA, the Roulette Wheel Selection (RWS) is used to select the individuals for reproduction according to their fitness values f_i, where f is the fitness value of the i^{th} individual in a population size N. A higher fitness valued individual gets bigger segments, which will have a higher probability P_i of being selected.

$$P_i = \frac{f_i}{\sum_{j=1}^{N} f_j} \tag{1}$$

This process is repeated until the required number of parents is gathered to perform the reproduction process.

Algorithm 2: RWS algorithm for selecting individuals based on their fitness values

```
public class doRWS
{
    int[] pop = new int[N];
    doube[] fitVal = new double[N];
    double sumFitness = fitVal[0] + fitVal[1] + …. + fitVal[N];

    do
    {
       selectParent();
    }while(reqNoOfParentCount == true);

    void selectParent()
    {
        double segment = Random.NextDouble() * sumFitness, fitnessVal = 0;
        for(int i=0, i< pop.length(); i++)
        {
           fitnessVal = fitnessVal + fitVal[i];
           if(fitnessVal >= segment)
           {
              pop[i];
              break;
           }
        }
     }
}
```

Tournament Selection (TS) is another way of selecting individuals based on their fitness values. The basic idea of this approach is to randomly select a group of individuals from the total of the population. A ‘tournament’ is performed among this group to select the best individual, based on the level of their fitness value, and it is then added to the mating pool. Repeated tournaments are conducted to fulfil the required number of parents for the mating process.

Algorithm 3: Tournament Selection Algorithm

```
Class tournamentSelection(totalPopSize, groupSize)
{
   bestInd = null;
   for(i=0;  i<=groupSize;  i++)
   {
      ranInd = TotalPopulation[random(1, totalPopSize)];
      if((bestInd == null) || (fitnessValue(ranInd) >   fitnessValue(bestInd)))
         bestInd = ranInd;
   }
   return bestInd;
}
```

In this research, Roulette Wheel Selection (RRWS) is used to select individuals as parents, based on their ranking positions. Like in RWS, an analogy would be where each individual is placed onto the ‘roulette wheel’, but in this case, the whole wheel segment is divided into four unequal parts giving the biggest segment to the Rank 1 individual, second biggest segment to the Rank 2 individual, third biggest segment to the Rank 3 individual and the smallest segment is assigned to the rest of the individuals as shown in Figure 3. Rank 1 has a higher probability of being selected than Rank 2, Rank 2 higher than Rank 3, and so on.

Algorithm 4: RRWS algorithm for selecting individuals based on ranking system

```
public class doRRWS
{
    int[] pop = new int[N];
   //end user (or) aesthetic measures decide ranks
   int rank1 = pop[x], rank2 = pop[y], rank3 = pop[z];

    do
    {
       selectParent();
    }while(reqNoOfParentCount == true);

    void selectParent()
    {
        int segment = random.Next(1, 100);

        // rank1 is given 35% of chance to be selected
        if (segment >= 1 && segment <= 35)
        {
           parent = rank1;
        }

       // rank2 is given 30% of chance to be selected
        else if (segment > 35 && segment <= 65)
        {
            parent = rank2;
         }

        // rank3 is given 20% of chance to be selected
         else if (segment > 65 && segment <= 85)
         {
            parent = rank3;
         }

         // 15% of chance to select the remaining individuals within the group
         else
         {
            parent = pop[random.Next(4,N)];
         }
      }
   }
```

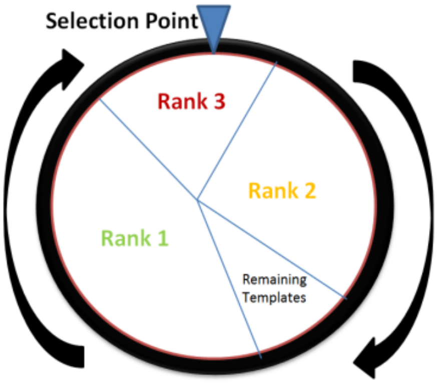


Figure 3. Roulette wheel selection sample – they are of each slice is proportional to its probability of being selected.

Other than generational methods (such as RWS, TS, rank selection, RRWS etc.), a steady state selection (SSS) is used in GAs to preserve fittest individuals by passing them on to next generations by replacing with least fit individuals. The main purpose of this selection method is to pass successful characteristics onto the newer generations taken from the offspring (produced from best individuals) by deleting poor fit individuals in the population group.

In this research RRWS selection method is used rather than RWS method because, according to Miller and Goldberg [32], if there are a low number of higher fitness individuals in a selected group, which may be possible in both RWS and TS methods, they could affect GA performance by taking an unnecessarily long time in finding the optimal solution. Researchers have also tried to find the best selection method by combining [33] and improving[32] [34] the existing selection methods.

2.1.5 Crossover

After the selection phase is complete, the reproduction process executes producing new offspring by using both crossover and mutation operators. Crossover performs the operations necessary to combine the information between two parents and produces offspring. During this process, depending on the crossover probability rate, either the parents will replicate themselves, or exchange their genetic information in the form of chromosomes to each other to form a new pair of individuals called offspring. Exchanging information can be carried out in many different ways, and most known techniques, such as single-point crossover, two-point crossover, and uniform crossover are described in this section.

At single-point crossover, the total size of each parent chromosomes (binary strings of genes), P_1 and P_2, is n. At a random position point, k, genes (binary bits) are exchanged to produce new offspring, O_1 and O_2, as $[P_1(1, k) + P_2((k+1), n)]$ and $[P_1((k+1), n) + P_2(1, k)]$ respectively, as illustrated in Figure 4.

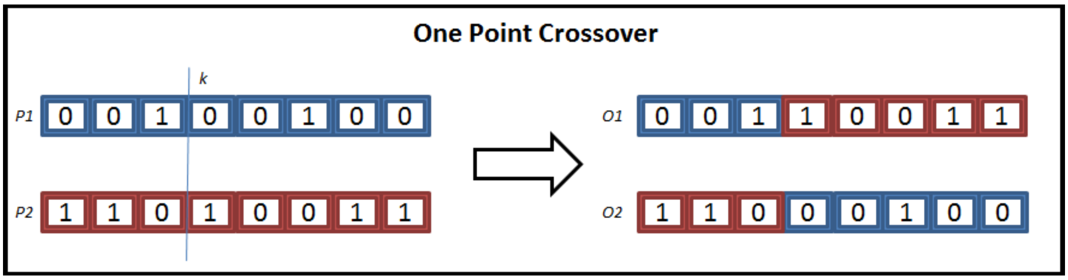


Figure 4. One point crossover – two Parent chromosomes, giving birth to two new Offspring's

In two-point crossover technique, binary bits are exchanged between parents P_1 and P_2 from their total size of binary string n, which is divided into three parts, with two random points, with positions *k1* and *k2*, producing a set of new offspring's, *O1* and *O2*, with new chromosomes binary strings as $[P_1(1, k_1) + P_2\{(k_1+1), k_2\} + P_1(k_2 +1, n)]$ and $[P_2(1, k_1) + P_1\{(k_1+1), k_2\} + P_2(k_2 +1, n)]$, as shown in the Figure 5.

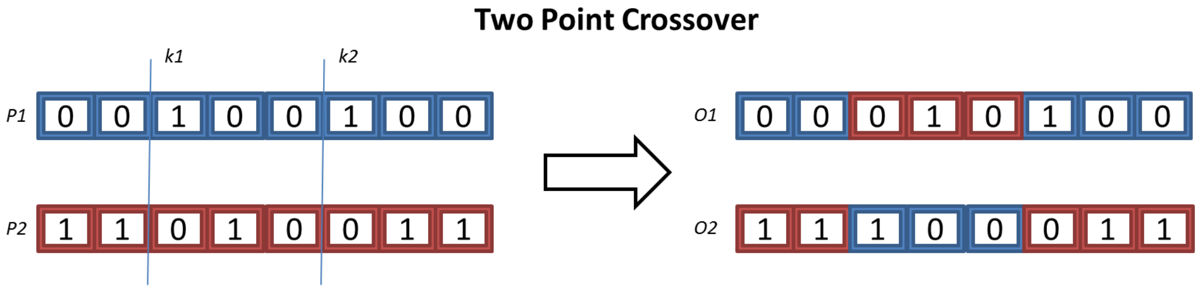


Figure 5. Two point crossover – two Parent chromosomes, giving birth to two new Offspring's.

In uniform crossover technique, at equal ratio levels, bits from both parents binary string are copied over to form a complete set of offspring's binary strings. For example, if the mixing rate is at 50%, then half of the genes are carried over from parent 1 and the rest half of the genes are from parent 2. This is described well by Eiben and Smith [35] using a coin toss. "Heads" means the binary bits from P_1 are assigned, and "tails" means the binary bits from P_2. Nature flips the coin, and based on the results, copies either the first gene from P_1, or the first gene from P_2. This process continues until the new offspring has an equal size of binary string to that of their parent’s binary strings.

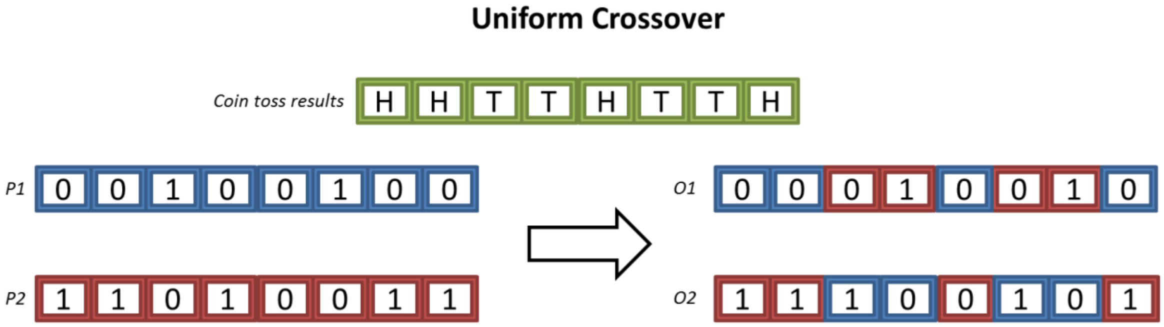


Figure 6. Uniform crossover process using a coin toss results

The techniques used in single, double and multi-point crossover are the same i.e. exchanging information between two chromosomes. But, according to Booker [36], the fittest individual chromosome may not necessarily contain the best part (genes) on the neighbouring subgroup. In the multi-point crossover, increased recombination (gene by gene mixing) of information could lead to exploration of the search space rather than exploitation directly at the initial stage [37].

2.1.6 Mutation

Mutation operation is performed to bring alleles into the new population group, in other words, brings potentially novel genetic information into the search space. This is done by altering genes on the newly created chromosomes, which generally happens after the crossover operation is performed. In the SGA process, at the beginning of the mutation process (based on the mutation probability rate) certain numbers of offspring chromosomes are selected. Then, at a random position on a binary string of each selected offspring chromosome, bits are flipped over to the opposite side, i.e. 1 to 0 or 0 to 1, as shown in Figure 7, giving a new property of the selected offspring. The unselected offspring properties remained unchanged and are added directly into the new population group.

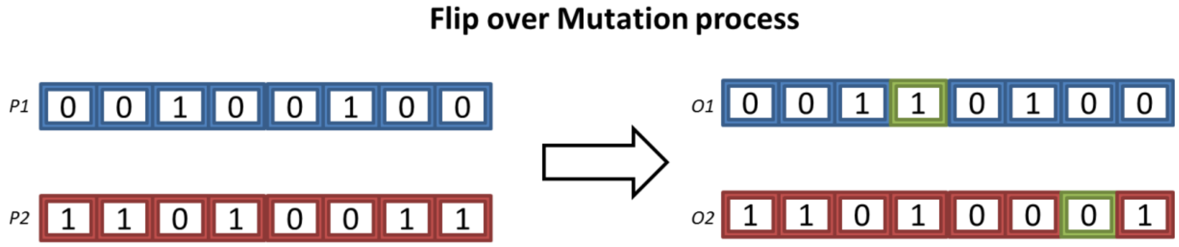


Figure 7. Mutation process – bits flipped over at random points

Typically, in SGA, the mutation rates are kept low from 0.001 to 0.05 [29]. This is to benefit from the exploitation of genes when mutation is at a low level. Otherwise the search space may increase, which results in more time being required in finding the solution [35]. Probability rates of both crossover and mutation rate effect performance of GA and a number of other guidelines are available in the literature by Goldberg [38] Srinivas and Patnaik [39] Grefenstette [40] Schaffer et al.[41]. In this research, the mutation operator with the least probability is used when aesthetic measures guide the evolutionary process of landscape designs and colour schemes. Furthermore, when using IGA fitness evaluation, the user can control both the mutation and crossover probability rates according to the results obtained from generation to generation.

2.1.7 New Generation

After the reproduction process is complete a new population is generated for further evaluation, called a first generation. The new generation replaces the initial population and fed back into the system to perform the fitness test, selection, and reproduction process until the second generation is formed. This process is carried out in a loop until termination criterion is reached using one of the following strategies:

1. When using IGA, the user decides when to end the experiment based on the results attained in the new population
.
2. When using GA, designer will set the termination criterion, based on highest fitness values which the individuals in the new generation must attain or end user sets the number of generations to run and when that limit is reached the GA process is terminated automatically.

In this research, all generations are cached, allowing the end user to revert back to previous generations and restart the experiment from any point if required. While using aesthetic measures as the fitness functions, the user has control to limit the number of generations. If the user is not satisfied with the results, they can set another limit of generations to be run and repeat until satisfactory results are achieved.

2.2 Terrain Generation

2.2.1 Representation of Terrains

2.2.1.1 Mesh

Mesh is one of the most commonly used methods for representing terrains in 3D space. The heights and depths within the mesh are well-suited, resulting into mountains and valleys respectively. It is generally formed when elevation points on solid polygons are triangulated into a 3D mesh, resulting into a large number of triangles and vertices, as shown in Table 1 - Step 3. Table 1 shows an example of creating real-world terrains, Rio de Janerio (Brazil), using a DEM (Digital Elevation Model) generated elevation points in an empty polygon.

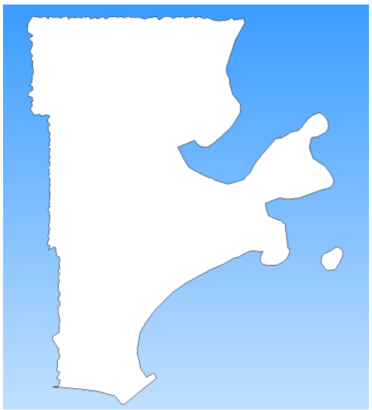
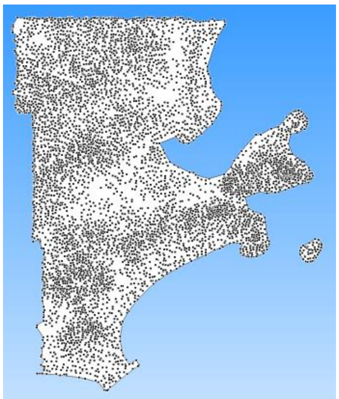
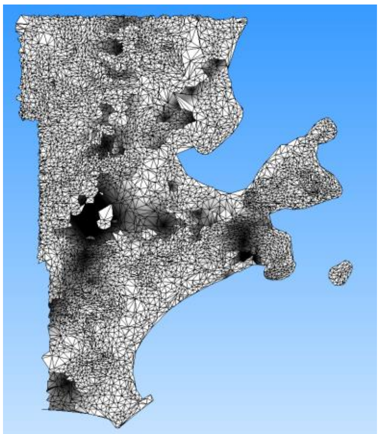
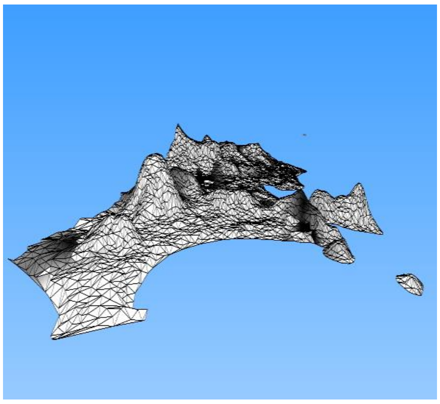
Step 1: An empty polygon 	Step 2: Elevation points within the polygon 
Step 3: Triangulated mesh 	Step 4: Formation of real world terrains 

Table 1. Formation of mesh using real world elevation points.

Advantages:

1. 3D modelling objects can fit anywhere in the mesh, especially on the terrain where position and altitude values are given.

2. Collision detection is accurately maintained over triangulated terrain mesh.

Disadvantages:

1. Mesh requires input in the form of common data formats such as Data Elevation Model (DEM), Digital Terrain Model (DTM), Shuttle Radar Topographic Mission (SRTM), local survey elevation details etc., for representing a real-world terrain design. Acquiring this terrain data can prove time consuming, and one might encounter permission restrictions from third-party source providers, etc.

2. When multiple elevation points are overlapped over the surface, it can be difficult to represent caves, overhangs or other vertical surfaces.

3. It is difficult to modify the terrain mesh after triangulation is done due to the complexity of the function that it is made with, i.e., by linking each polygon to one another.

2.2.1.2 **Height maps**

Height maps are used to represent terrains. They are commonly used in most of the current scenery/terrain generation software. They are presented in 8-bit greyscale bitmap, where a colour pixel value (0 - 255) is calculated in terms of elevation point. White coloured pixels represent the highest elevation point, and black coloured pixels the lowest elevation point; while sometimes there can also be a negative point. For example, Figure 8 illustrates a converted 3D landscape image using a height map, where the white pixel area is generated as mountains, and grey/black pixels form a seabed with different levels of depth contours.

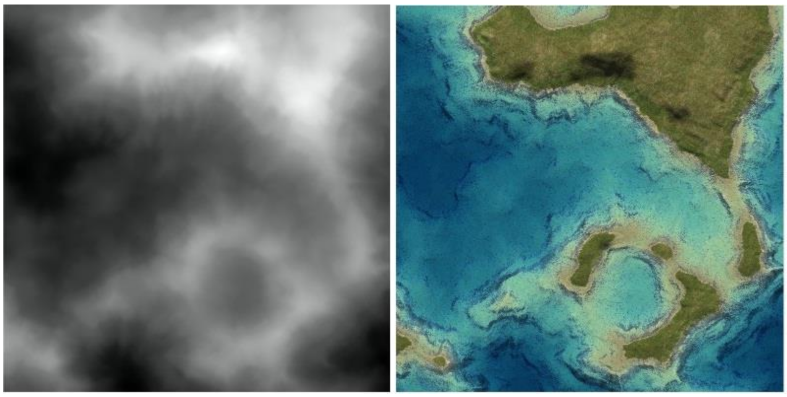


Figure 8. Height map conversion into a digital landscape design

Advantages:

1. Information on the terrains can be easily stored and shared quickly, due to its smaller size and lower memory requirements.

2. When the object location is given in the height maps, collision detection is easily achieved through checking a few triangles.

Disadvantages:

1. A typical height maps consist of a large number of polygons and triangles, which make any computer graphics engine run into difficulty when rendering settings at the finest resolution.

2. When multiple heights are overlapped over the surface, it can also be difficult to represent caves, overhangs or other vertical surfaces.

3. It is difficult to visualize height field generated landscapes in a spherical shape when the viewpoint is set to flight mode or at the top angle. This is due to the rectangular shape of maps, which are not able to resolve globe-shaped objects.

2.2.2 Terrain Generation Methods

2.2.2.1 Editing tools

Sculpting is an easy way of generating terrains. Software such as Photoshop [42] can be used for editing or painting terrain images. Computer-aided modelling is one of the most flexible techniques for the generation or designing of terrains. Editing software like Maya [43], and Blender [44] provides an intuitive means through which a user can build realistic terrains. However, the software toolset available in such programs requires a great deal of manual input from designers. The users also need to be trained to a high standard if they are to master the skill sets needed to create functional terrains.

2.2.2.2 GIS

Geographical Information System (GIS) [45] is used to create maps including terrains, which are integrated with real-world information. GIS systems gather various data types in a number of ways; for example, through satellite images, using remote sensors and surveys, etc. Its data format, DEM, consists of a uniform matrix of terrain elevation values with respect to latitude and longitude positions in order to create a real-world terrain structure. DEM is used in many programs like MicroDEM [46] and Creator [47], as a means of displaying real world terrains. This is useful in simulation for military training, as it can replicate real-world locations. However, the process can be time-consuming and may pose difficulties when finding accurate data to fulfil the requirements. There may also be copyright and privacy issues in using such a technique, as terrain requirements often go beyond existing “real” world examples.

2.2.2.3 **Fractals**

A fractal landscape is generated by a stochastic procedure that replicates the appearance of natural terrain. Many natural features exhibit some form of statistical self-similarity that can be modelled by fractal surfaces [48]. Moreover, disparity in surface texture provides important visual indicators as to the slope and alignment of surfaces, and fractal patterns can help mimic these natural looking visual effects [49]. A common fractal technique to generate such a landscape is to employ the random midpoint displacement algorithm [50], in which a square is subdivided into four smaller equal squares and the centre point is vertically offset by some random amount. The process is repeated on the four new squares, and so on, until the desired level of detail is reached. While fractal generation techniques meet many of the requirements of terrain generation applications, user intervention is needed in order to set the vast number of parameters, such as feature scale, steepness, roughness, displacement amplitude, displacement offsets etc., that control the fractal procedure to evaluate and possibly refine the resulting output.

To automate this aspect, this research proposes an evolutionary algorithm and aesthetic fitness measure that can reduce the burden on users wishing to generate realistic landscapes by adjusting values of the required fractals of a terrain automatically.

2.2.3 Terrain Generation Software

Currently most software applications that generates landscape designs aims to require less human input and to produce more effective results. This is possible, to a certain extent, if a user should have at least an intermediate level set of competencies in using computer applications and modelling. Most of the software is designed for graphic designers, artists, game developers, movie makers, and enthusiasts.

2.2.3.1 **Terragen**

Terragen, a fractal landscape and animation generator of Planetside Software, creates a photo-realistic visualization of landscape designs and natural environments including sunsets, clouds, skies and water sceneries with real-time rendering. It is used for creating visual effects in, games [51], magazine covers [52], TV commercials [53], movies [54] etc.

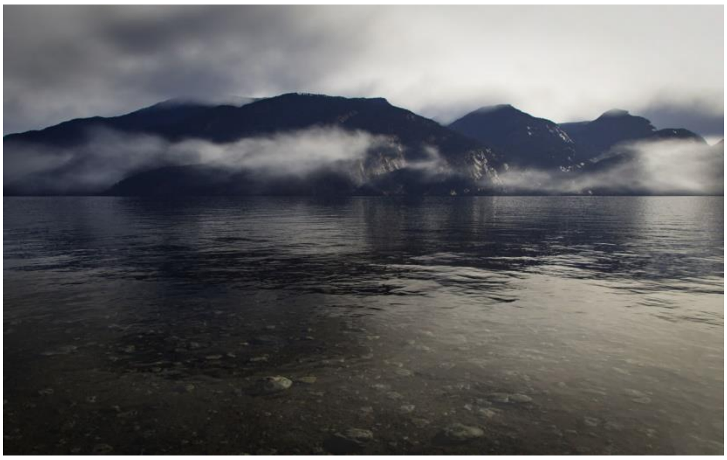


Figure 9. A scenery generated using Terragen software

Terragen reads in excess of 800 parameter values in an XML format called TGD, and generates their graphical representation in the form of an image. It requires users to set some 800 values, as shown in figure 42, to define the properties of a landscape is, as already noted, a complex and time-intensive task. Most users will experience difficulty in creating sceneries using Terragen software for the first time, unless, or until they are familiar with all the attributes and their functions. Learning about attributes may require more practice, patience, and time. A thorough investigation of the rendering parameters is required, because modifying parameters without knowing their functionality might vastly increase the normal rendering time. It may also affect the quality of the final output. The user needs to go through many tutorials in order to understand every step, and experience each attributes' values sensitivity by rendering each time the value is changed. For example, a slight change in water roughness value (0.3) may produce a huge difference to the outcome of water effects as shown in figure 40. The other examples of parameter effects on same scenery are explained in section 3.3.1.

2.2.3.2 **Vue 8 Studio**

Vue 8 Studio [55], by E-on Software, is a scenery generation tool helps 3D designers to create digital landscape designs. It is a great tool for sculpting procedural terrain via a 3D sculpting brush. It has more realistic shadows, clouds, water effects; it offers rigged meshes, an easy planetary navigation system, and a variety of other features. It can competitively produce images that are close to those produced by Terragen with excellent image clarity and photo-realistic scenery. Figure 10 shows its accuracy when simulating natural looking landscapes.

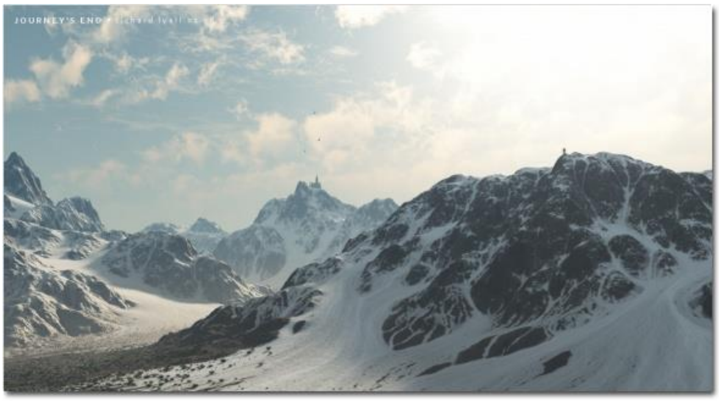


Figure 10. Landscape design generated using Vue 8 software

Going from an empty piece of scenery to a fully-animated landscape design, the user will notice that every step involved in this application is well-organized and in intuitive order. The user with intermediate competencies in using computer applications can learn all the tools and procedures needed by following the tutorials available. However, basic users, especially those who are not experienced in 3D modelling or painting, may find it difficult to use this software.

2.2.3.3 **Blueberry 3D**

Bionatic’s newer version of Blueberry 3D [56] has a terrain editor which can create huge, dynamic, real-time procedural terrain with a continuous LOD. This software is mainly used in military training simulation, as it holds dynamic elevation data over the ground level in a realistic and fully-automated way. A good example of dynamic elevation data is shown in figure 11, where the trainer can dig or destroy terrain over the ground level in real-time simulation, making it suitable for testing player survival capabilities during exercise time. Most of the output sceneries generated by Blueberry 3D will have more realism with real world data and a good level of photo-realistic features.

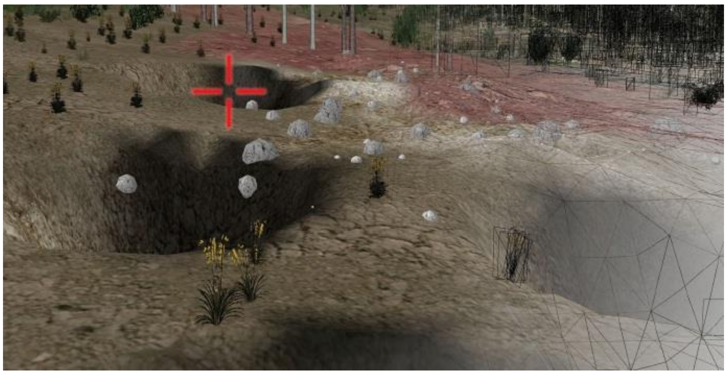


Figure 11. Editing terrain mesh in real-time during a course in simulation

Blueberry 3D terrain editor is mainly designed for professional users. In order to become proficient in this program, it is necessary to attend special training classes in creating scenarios with landscape designs. Tutorials are not as helpful in this instance, as it is more difficult to get to know each tool and their functionality while creating sceneries.

2.2.3.4 **Terra Vista**

Terra Vista [57], a Presagis product, can be used in the most basic and the most complex terrain applications. It can visualize real-world terrains, maps and 3D models for simulator mission's rehearsals, operational use and many more applications. In order to create sophisticated terrain models and other visual requirements, Presagis offers special training for designers to make them as proficient at using tools and wizards as possible. Figure 12 shows a fully-implemented landscape design with real world terrains and buildings alignment matching all vertices with accurate elevation values.

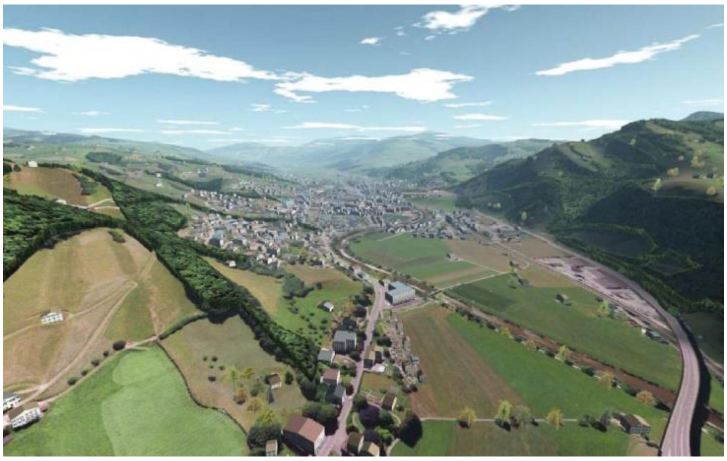


Figure 12. Terrain generation scenery made using with Terra Vista

Terra Vista comes with many other helpful wizards and tools from Creator, which is helpful in every step while developing area database for simulators. For example, it takes less than a minute to create a building, bridge or runways using building wizards. These are all available with this software package. However, attending training classes is necessary for a basic user to gain a good understanding of every tool and procedure, while creating area database development that contains terrains.

2.2.3.5 **World Machine**

World Machine [58] is another popular tool for editing and creating terrains using a procedural level other than painting, the most common method used in other applications. The user needs to determine the overall appearance of the terrain, which will then be applied automatically to all other terrains that are generated. It has real-time rendering of terrains, in which the user can easily see and identify the changes made by editing parameter values within the user interface. World Machine produces realistic digital world, as shown in figure 13, with atmospheric conditions.

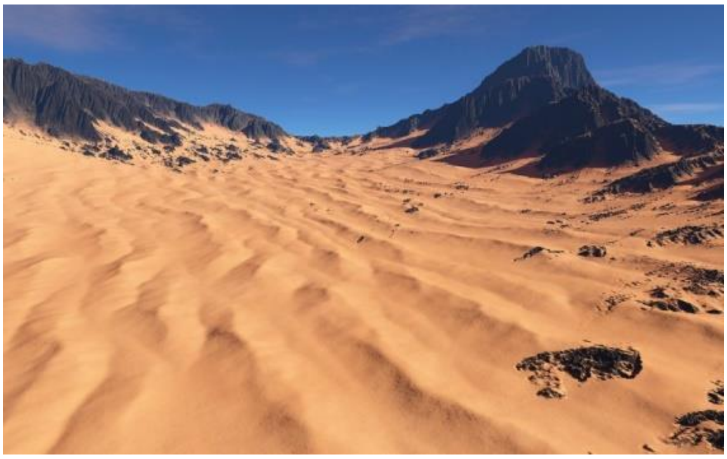


Figure 13. Scenery generated using World Machine

World Machine has a facility which allows users to share work in the form of macros. A macro is a recorded programming code that holds the entire network device’s information in one repository, consisting of predefined options, controls and parameterized input values. In this way, users can share their self-created effects in a simple way to create a world with determined terrains. However, while these painting skills are easy to master, they are very labour intensive and also user has to possess a high level of knowledge with regard to modelling software.

2.2.3.6 **Bryce 7**

Bryce 7 [59] is a software package that can convert imaginary ideas into virtual reality sceneries. It is mainly used by artists, animators, web designers and multimedia producers. It has a wide variety of controls, which can create a number of custom terrains and then landscape these designs using a terrain editor. Sky and clouds are well-maintained, allowing the user to include stars, comets, moons, rainbows, cloud motion, cumulus formations and so forth. It also has a robust real-time advanced rendering system, which will help to see effects and defects in the design during the process. The end result of a landscape created by Bryce 7 software is outstanding virtual realistic sceneries, as shown in the following figure 14.

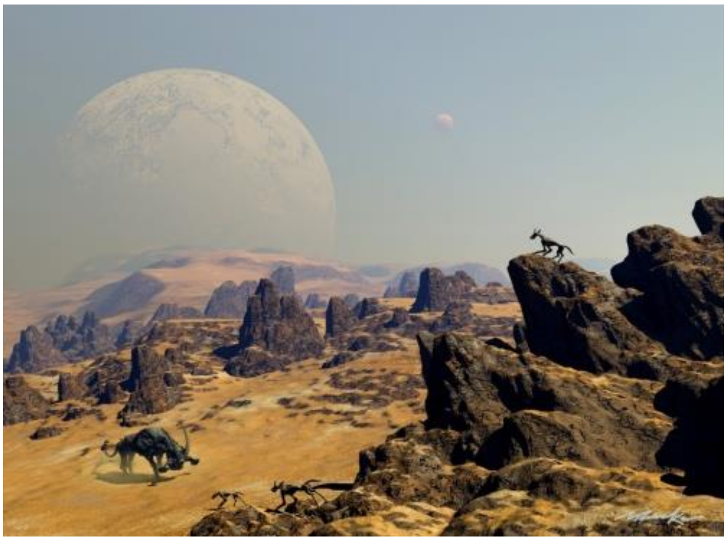


Figure 14. Landscape design created using Bryce 7

Using Bryce 7 requires a high level of skill. There are many parameters involved, which require constant modification while creating sceneries. For a normal user, it would be very difficult to understand the whole process.

	Terragen	**Bryce 7**	**Vue**	**Blueberry 3D**	**World Machine**	**Terra Vista**
Scripting/XML support	√	×	×	×	√	×
Fractal terrain generator	√	√	×	√	×	×
Multi-threading support	√	√	√	√	√	√
Free trial available	√	√	√	×	√	Upon request
Command line execution support	√	×	×	×	√	×
3rd Party Network render farm supporter	√	√	×	×	×	×

Table 2. Scenery generation software features table

Based on the results of features table shown in table 2, Terragen possess all the necessary features that are required for this research to use it as rendering software for generating sceneries during the evolution of landscape/terrain generations is performed. Here, XML files are used to communicate between Terragen and EC framework and vice versa. Other than Terragen software, the framework developed in this study can easily be editable to work with any other scenery generating software that supports XML/scripting, fractal terrain generation and with command line execution support.

2.2.4 Related Information

2.2.4.1 Automatic/procedural content generation techniques

The articles discussed below support the argument that moving from traditional handcrafting of terrain/game content to automatic terrain generation results in less investment and developers resources. H. Häggström discusses in the paper "*Real-time generation and rendering of realistic landscapes*" [60] the ability to generate realistic landscapes in real time.

The author argues that real time generation of a landscape can be achieved by storing data compactly, such generation rules, parameters, and random seeds, and using various fractal and procedural algorithms to expand these inputs into the visible part of the landscape. In modelling landscapes the paper presents two distinct applications based on their requirements on interactivity and source data. The former is the applications used in computer and video games whereas the second application is based on GIS. The paper suggests that landscape designers either use declarative and procedural in specifying the landscape. The declarative approach defines every height point in the terrain, position and properties of every object in the landscape whereas the procedural approach uses algorithms that produce varying, natural looking data.

Olsen focuses his investigation on the generation of terrain specific to eroded terrains in computer games [61]. Unlike using predefined terrains or runtime generated data based on fractal noise techniques the author argues that the availability of computer programs provides opportunities for designers to simulate erosion processes. The author uses two types of erosion algorithms thermal erosion (sometimes referred to as thermal weathering) and hydraulic erosion. Using computer games of the real-time strategy genre, a set of desirable traits were condensed into an erosion score that, together with the strict real-time requirement, was used to evaluate methods of terrain synthesis and implementations of two of the classical erosion algorithms. The author found that methods for evaluation together with modifications to the synthesis of the base terrain could be used to fine-tune the terrains to meet playability criteria.

In “*Generation and visualization of terrain in virtual Environments*” [62] Tisovcik examines the most frequently used algorithms used in terrain generation to resemble existing terrains. The author discusses the processes involved in terrain generation such as terrain scanning, terrain modelling and generation of terrain and how these processes can be combined in a manner that best suits the application. The author also provides a history of the notable uses in terrain generation. The paper discusses ways in which terrain data can be stored in RAM such as the polygon mesh (Triangulated irregular network and Regular height field and heightmap), Streaming mesh, voxels, and combination. The author provides a framework through which VRECKO users can adopt the various terrain generation algorithms.

In “*Terrain Simulation Using a Model of Stream Erosion*” [63] the paper takes a look at terrain generation by maintain a relief of the natural landscape which is primarily created by water erosion of landscapes. The model developed by the authors is derived from topographic structures created by a drainage system and its tributaries. The authors use information from empirical erosion models used in geomorphology. The model includes modelling the drainage network, modelling the surface, rendering the surface and implementation of the model. The advantage with the model is that it requires less information to represent the entire drainage system as it uses empirical models from geomorphology are used as a basis for the modelling and therefore does not need explicit modelling.

In "*Controlled Procedural Terrain Generation Using Software Agents*" [64] the authors procedurally generated content possess novelty such as:

1. It contains an element of randomness and unpredictability.
2. Structure: is not merely random noise but contains larger structures.
3. Interest: has a combination of randomness and structure that players find engaging.
4. Speed: can be quickly generated and controlled: can be generated according to a set of natural designer-centric parameters.

The authors perceive software agents as an agent that perceives its environment through sensors and acts on it through effectors. All agents are given autonomy, other than some constraints on what the agent is to produce. These agents are used in three distinct phases that include coastline, landform, and erosion. The agent-based generation provides content meeting designers needs and can modify the agent constraints to fit what they would want to develop.

In paper "*Procedural Generation of Terrain within Highly Customizable JavaScript Graphics Utilities for WebGL* [65]*"* authors focus on the use of procedural generation of terrain using algorithms which to authors' view provides opportunities to create unique areas and models. The research focuses its experiments to the limitations of the WebGL platform. According to the paper, the procedural generation using a set of pseudo random numbers allows the developer to create unique or predefined content. The implementation of this approach is through use of the two steps referred to as the diamond and square steps in changing the height value of a location in a square area. The paper concludes that procedural generation using java script has significant reduction in bandwidth requirements and this is particularly useful in web-oriented scene generation applications.

In a discussion on the concept of terrain generation, Génevaux. J et al., [66] approach it form a hydrological point of view in the paper "*Terrain Generation Using Procedural Models based on Hydrology*". This paper discusses the limitations of existing techniques such as sketch-based methods which involves manual editing and tends to be tedious. Procedural methods as well as physics based algorithms, often lack controllability. Adopting a procedural model, the authors use river networks for terrain modelling where the user interactively provides the contour of the generated terrain, river mouths, some river parts, and input parameters. The processes involved include river network generation, river classification, terrain model generation and terrain tree generation. The final product is that the terrain generation is derived from the underlying hydrographic network, and it guarantees that the construction satisfies hydrographic properties.

Kamal and Uddin [67] view terrain generation as being done for a particular purpose such as a terrain that is similar to a specific area rather than a random one in "*Parametrically Controlled Terrain Generation*". The authors explore a parametrically controlled artificial approach to terrain generation of a mountain peak of a specified area. The authors present the different parametrical control in existing terrain generation techniques which include; Midpoint Displacement (MPD), Erosion Algorithms, Fault Algorithms, Bivariate Normal Model and Repeated Magnification and Probing. The paper however limits its experiment to only one mountain peak but suggests that this should promote interest in generating several terrains in specified areas as from a satellite photograph.

In their paper "*Procedural content generation for games: a survey*" [68], authors focus on the Procedural Content Generation for Games (PCG-G) as an application that uses computers to generate game content which can provide exciting scenarios for individual players. The authors highlight the challenge of game content generation is it requires: a large number of staff including artists, designers, programmers, and audio engineers. The paper presents six classes of game content that can be generated procedurally. These include: game bits, game space, game systems, game scenarios, game design and derived content. The paper discusses the different methods of PCG-G which include; Pseudo-Random Number Generators (PRNG), Generative Grammars (GG), Image Filtering (IF), Spatial Algorithms (SA), Modelling and Simulation of Complex Systems (CS) and Artificial Intelligence (AI). The paper further elaborates the manner in which these methods can be used for content generation.

In "*A survey of procedural content generation techniques suitable to game development*", [69] the authors of the article focus on the generation of quality game content. They contend that in order to develop an environment for the games. It requires several artists and 3D modellers to develop content. They argue that there should be incorporation of procedural techniques in content creation which can be adopted by the team in the design stage. These techniques are grouped according to their resulting content which includes rivers and terrains, continents and roads and rivers and cities. The authors further categorize the procedural techniques based on whether they are assisted (heavily relies on human intervention/guidance in order to produce the desired results) or non-assisted (requires a few or no human intervention/guidance in order to produce the desired results). The article focuses on three dimensions of the environment content.

Raffe and Zambetta focus on procedural terrain generation processes through a lens of evolutionary algorithms (EA) in video games [70] in "*A Survey of Procedural Terrain Generation Techniques using Evolutionary Algorithms*". The authors argue that development in terrain generation have adopted Search-Based Procedural Content Generation (SBPCG) where search algorithms (primarily EA) are used to procedurally generate a wide variety of game content. Although there are other established techniques in the market they argue that their random output only means that they can be utilized by fewer game types. Adoption of the EA will assist in exerting control on the procedural terrain generation whereby developers can react to the preferences of players and allow similar terrains to be created and refined. The paper discusses the evolution of procedural terrain generation by focusing on past adoption of EA which include; Ong et al. (2005) [71], Frade et al. (2009) Togelius et al. (2010) [72], Walsh & Gade (2010) [23], Raffe et al. (2011) [73]. The article gives advantages and disadvantages of the different approaches concluding that there should be further research on EA in procedural terrain generation.

2.2.4.2 **Automatic content generation using GAs**

A paper by Professor Peter Guth of the Oceanography Department, U.S. Naval Academy [74] observes that despite the existence of several terrain generation techniques in the market, fractal-based techniques are still dominant in the video games sector owing to their ease of implementation. However, they point to the inability of fractal-base techniques to develop exotic terrains while utilizing their full creativity. They propose the ability of the Genetic Terrain Programming (GTP) allows the evolution of Terrain Programmes (TPs) based on aesthetic evolutionary design with Genetic Programming. The authors outline the goals of GTP as capable of generating diverse features and terrain types, both aesthetic and realistic, extensibility, intuitive to control, automated generation with arbitrary resolution and low requirements of human input. M. Frade et al., showed continuous improvement in creating terrain generation using GP and evolutionary methods with algorithms, fitness function based on accessibility using evolution method [75], fitness function based on obstacles using evolution method, produced a game using genetic terrain programming called "Chapas " [76] and a new approach to improve user experience of modelling video games landscapes by using GTP [77].

Terrainosaurus [78], a thesis by Saunders presents terrain generation through the use of real – world terrain data as raw material and use of AI to control the generation process. This study is aimed at the needs of "studio" users: artists, animators, and simulation and video game designers, people who typically have high goals for realism and quality, have powerful computing resources at their disposal, and do not have real-time processing constraints. The advantages of using the *Terrainosaurus* paradigm is that it allows the user to have more control on the shape of the terrain, user-centric design paradigm, uses user-provided, real-world elevation data as raw material and genetic algorithms where the user can design and manifest the desired terrain.

Ong, Saunders and Legget [71] in "*Terrain generation using GAs*" begin with citing limitations in the existing procedural algorithms for terrain generation which are predominantly 2D while also limiting the type of terrains to be generated. They provide a certain manageable level of control over specific terrain types and approximate regions that the terrains should occupy. The authors give different categories of existing terrain generation techniques. These include, sculpting techniques, geographic information systems, physically-based techniques and the fractal techniques. The author's breakdown the terrain generation into two distinct phases the terrain silhouette generation phase, and the terrain height field generation phase. The breakdown into phases allows for greater control into the shape and layout of the terrain. This approach utilizes both user input mechanisms and approaches along with generated data.

Cohen focuses on the design of cities through the blending of different city designs through user guided development of real existing cities. In, "*Citybreeder: City Design with EC*" [79] the author introduces the concept of Evolutionary Computation which is used to discover the genetic representation of existing city designs derived from real city data. This approach is feasible as it allows developers to design cities through the combination of different features of existing cities. In order to address these challenges in city design, the author introduces and supports the use of the Citybreeder system. The author hopes to create interest in similar systems in the design of cities adopting multiple designs in creating cities by borrowing the different features of cities.

The paper "*Evolutionary Learning and Search-Based Content Generation in Computer Games"*[80] focuses on the challenges of developing the AI of the non-player characters (NPCs). The author argues that modern computer games require a form of AI system which shows human-like behaviour to enhance the gamer's experience. The author suggests that adoption of computational intelligence in terrain generation unlike traditional approaches, saves on time, workload and resources. Computational Intelligence is a field of AI which includes techniques and mathematical models which are inspired by nature. The thesis also investigates the evolution of first, non-player characters which include offline learning, on-line learning and transfer learning. Second, the content generation is different into three game types; racing games, first person shooters, and platform games. The author finds that these approaches can also fit in the commercial games sector.

The paper, "*Evolving Content in the Galactic Arms Race Video Game [80]* " introduces cgNEAT, content-generating NeuroEvoluation of Augmenting Topologies algorithm, where players can create their own game contents to satisfy their special needs, significantly reducing the cost of creating games and increasing the replay values of the games. In this paper they implemented GAR, Galactic Arms Race, to create unique weapon system that is evolved in the game by the players.

2.2.4.2.1 EC applied on digital artefacts driven by aesthetic measures

The authors put a case forward for fitness assignment within evolutionary art is unsupervised evolutionary art, whereby a computational fitness function assigns a score to an artefact without human intervention. EC has demonstrated its potential for Evolutionary Design (ED) producing solutions that are competitive, and even superior to those developed by human experts resulting in patentable inventions [81] The most common aesthetic measures used by many researchers in the field of evolving arts are Benford's Law (BL) [82], Information theory [15], GCF [16] and Ross & Rolf -bell curve (R&R) [11].

The paper "*Benford's Law in Image Processing*" [83] discusses BL of "anomalous digits" predicts the frequency of appearance of the most significant digit (MSD) for abroad range of natural and artificial data. The authors focus is on the works of J. M. Jolion [10] in "*Images and Benford's law*", who shows that BL holds reasonably well in gradient images and in pyramidal decompositions based on the Laplace transform showing that images situations change when they are transformed using the Discrete Cosine Trans- form (DCT). The paper present a generalization of Benford's law, based on Fourier analysis that leads to a much closer fit to the observed digits frequencies. The authors confirm that BL can be employed for steganalytic purposes in images, that is, for detecting whether a certain natural image contains a hidden message.

The paper, "*Using Aesthetic Measures to evolve Art*" [84] investigates and compares three aesthetic measures in an art system. The measures include; BL, GCF and Information Theory. The authors adopt the Arabitat (Art Habitat) software environment to investigate evolutionary art. The authors conclude that the use of different aesthetic measures clearly results in different 'styles' of evolutionary art. The differences observed in the images are also attributed to the different aesthetic measures. The Global Contrast Factor was found to have the narrowest scope compared to the other two as it only gives high scores to its images and gives lower scores for other images.

In the paper "*Comparing aesthetic measures for evolutionary art*" authors, den Heijer and Eiben [85] explore and compare four aesthetic measures within the context of evolutionary art. The presentation revolves around the use of Computational Aesthetics in making applicable aesthetic decisions as aptly as humans. The researchers use the same Arabitat software environment to investigate another four aesthetic measures:

1. Machado & Cardoso's combined aesthetic measure of Image Complexity (IC) and Processing Complexity (PC) [15]

2. Ross & Ralph (bell curve) [11]
3. Fractal dimension [86]
4. Combined of above three aesthetic measure by using weighted sum

The authors conclude that the use of different aesthetic measures clearly results in different ’styles’ of evolutionary art. Further, differences observed in artistic styles are directly related to the aesthetic measures employed. The fractal dimension is less suitable as a universal aesthetic measure compared to Machado and Cardoso, Ross and Ralph which possess a varied output and appreciated work by others.

In the paper, “*Modelling human preference in evolutionary art*” the authors [87] focus on four established aesthetic measures in interactive evolutionary art to model human preference discussing their evolution and how different users interacted with a simple evolutionary art system and fully drove the selection process. The four aesthetic measures investigated are Measure R based on Ralph's work [11], measure MC based on Machado and Cardoso's work, measure BZ based on Birkhoff and Zurek's [88] work and measure S based on Shannon entropy. The authors argue that once a combination of measures that models increasing human preference during interactive evolution is identified, automatic evolution is provided with a suitable fitness evaluation method.

In the article “*Evolving Art using multiple Aesthetic Measures*”, den Heijer and Eiben [14] discuss the possibility to combine the effect of multiple aesthetic measures concurrently using a Multi-Optimization Evolutionary Algorithm (MOEA) which involves the influence of different aesthetic measures can be combined into the same image. This approach will allow for evolving of images with different properties. The measures used are BL, GCF, and R&R with the Arabitat software environment in which it investigates evolutionary art. The authors find that it is possible to combine different aesthetic measures which may also not guarantee success with the combinations resulting in better displayed images.

Rigau, Feixas and Sbert [89] propose an informational dialogue with van Gogh’s artwork showing a significant consistency between the proposed aesthetic measures and period-styles, and proposing tolls that can be used to study an artist’s work and detect specific features which could not be noticed by the observer. The authors adopt three tools for their research; the entropy of the palette, the compressibility of the image, and an information channel to capture the basic structure of the painting. The authors conclude that the measures investigated can help to quantify the differences between the different styles and the evolution of a painter, and also show the way an artist used the colours of the palette to outline elements of a painting.

2.2.5 Summary

This chapter offers an overview of the existing tools, procedural techniques, efforts to implement GAs and aesthetic measures in the field of EC for the generation of terrains. However, as demonstrated, there are significant drawbacks in relation to usability of tools, particularly with regard to user fatigue and the time it takes to gain a familiarity with the necessary processes. In addition to an account of existing tools, various techniques were examined, in particular, GAs and aesthetic measures to provide a mixture of procedural terrains, scenery generation software's and aesthetic measure implementation to evolve landscape designs using EC. This novel approach offered by this research removes these issues by offering users a more intuitive approach to these activities.

2.3 Website colour scheme generation

2.3.1 Representation of colours

In computing, colour can be represented in a number of ways. One of the most frequently used methods to specify a colour is in RGB code. RGB is a set of three primary additive colours – red, green, and blue – that together can form any desired colour ranging from one to sixteen million colours when they are mixed with each other. For example, when RGB values are at (0, 0, 0), they form the colour black and at (255, 255, 255), they form the colour white. In between these values, for each variation in RGB value, they form a new colour, for example, (255, 128, 255) as pink, (255, 255, 0) as yellow, (255, 128, 0) as orange etc.

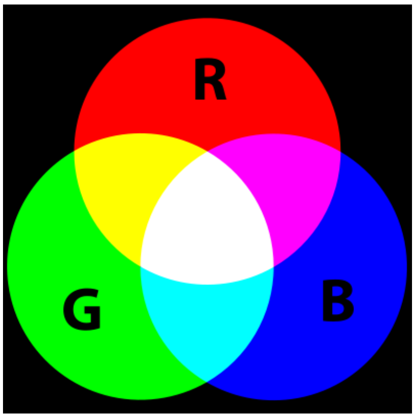


Figure 15. RGB colours overlapping to form different colours

Other than RGB code representation, especially in the field of website designs, hexadecimal colours codes (HEXCC) are mostly used due to their single code representation. They are specified by a three byte number format followed with a "#" symbol. Decimal values in RGB ranging from (0-255) are converted to hexadecimal values when represented in HEXCC.

Each byte represents red, green and blue channel values individually as follows:

- First byte holds = R decimal value (50) = in hexadecimal value (32)
- Second byte holds = G decimal value (100) = in hexadecimal value (64)
- Third byte holds = B decimal value (200) = in hexadecimal value (C8)
- => RGB(50 100 200) is converted into HEXCC format as "#3264C8"

The following table differentiates colour representations between humans and computers, and also how they are stated in different colour codes:

Sample	**Human Language**	**Machine Language**			
		RGB	**HSB**	**CMYK**	**HEXCC**
🟥	Red	(255 0 0)	(0° 100% 50%)	(0 1 1 0)	#FF0000
🟩	Green	(0 255 0)	(120° 100% 50%)	(1 0 1 0)	#00FF00
🟦	Blue	(0 0 255)	(240° 100% 50%)	(1 1 0 0)	#0000FF

🟨	Yellow	(251 246 30)	(59° 97% 55%)	(0 0.0199 0.88 0.0157)	#FBF61E
🟪	Pink	(246 72 225)	(307° 91% 62%)	(0 0.707 0.0854 0.0353)	#F648E1

Table 3. Specifying colours in both human and computer languages.

2.3.2 Colour Scheme Generation Tools

Colour schemes are important in a website, as they dictate the overall look and feel of the design in the first instance. Not all colour schemes created by humans may not perfect in terms of readability for the end-users. There are some existing techniques that have been devised to inform users, such as the colour wheel, and a variety of tools. Some of the tools that are listed here can actually extract bright colours from an image and create a colour scheme automatically for the user. The entire process is relatively straightforward, whereby the tools create a colour palette based on the selected colours, before applying this scheme to the website.

Even though the process is simple, there are some drawbacks to this method:

1. It is time consuming, and users may become fatigued or lose interest while selecting colours manually for an entire website. As for web design, it is not just about the selecting of favourite colours, but also the selected colour combinations need to be appropriate across the entire site.

2. There is also a lack of test/checks in relation to readability. The colours selected by a designer may not satisfy the end-users regarding the readability conditions, especially for vision impaired individuals.

2.3.2.1 Using Colour Wheel

Isaac Newton designed the colour wheel based on seven colours that are emitted from a prism when light passes through [90] as shown in figure 16. Since then, it has become a model for many artists, painters and now for graphic designers to generate colour schemes based on those seven colours. The corresponding colours can be easily found by treating their opposite colours in the wheel as their combination colours. With this theory, the user can simply prepare a set of colour combinations pairs while creating a colour palette for website design.

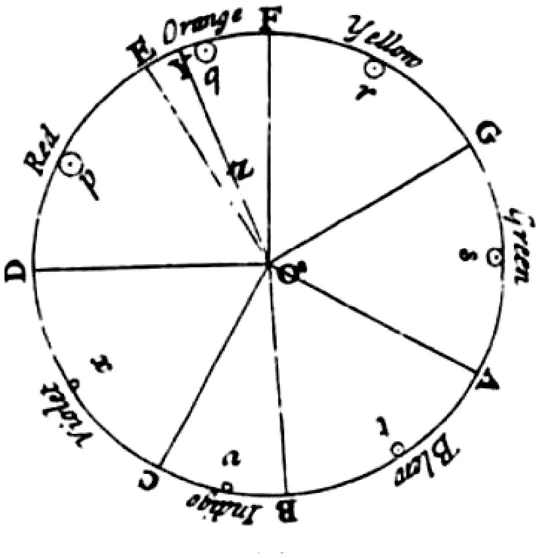


Figure 16. First colour wheel invented by Newton with seven colours.

Based on Newton’s colour wheel, there are many similar colour wheels that have evolved by adding tertiary colours into the wheel. Tertiary colours are formed when secondary colours are mixed with one another and secondary colours are formed when primary colours are mixed with one another. For example, here the primary colours (red, yellow and blue) form the secondary colours (yellow = *red* + *green*, orange = *yellow* + *red*, and violet = *red* + *blue*) and with the same process secondary colours form tertiary colours into (yellow-orange, red-orange, red-violet, blue-violet, blue-green and yellow-green), as shown in figure 17.

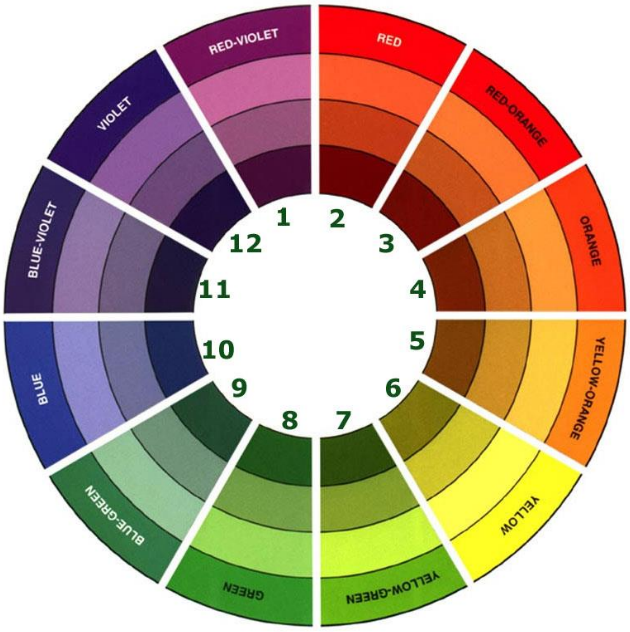


Figure 17. A colour wheel [91] describing how secondary and tertiary colours are formed by using primary colours (red, yellow and blue).

By using 12 sets of the colour wheel, users can create a wide number of colour schemes depending on their requirements, such as:

1. In colder regions people prefer warm bright colours like red and yellow, whereas warmer region people prefer cooler, less saturated, colours such as blue and green [92]. Depending on the region, using the colour wheel as shown in Figure 20, colours numbered from 1 to 6 are suitable for colder region countries and 7 to 12 are suitable for warmer region countries.

2. The analogous colour combination scheme can be created using colours adjacent to one another. For example, a set of colours from the colour wheel labelled as (1, 2 and 3), (2, 3 and 4), (3, 4 and 5) … (10, 11 and 12).

3. The complementary colour combination scheme can easily be created using opposite colours in the colour wheel. For example, pair of colours from the colour wheel labelled as (1 and 7), (2 and 8), (3 and 9) … (6 and 12). It is also possible to find a set of three complementary colours at once by using symbol “Y”. For example, set of (2, 9 and 7) or (2, 10 and 6), (5, 10 and 12) or (5, 9 and 1) and so on.

The colour wheel is useful in the field of interior design, painting and in graphic design. But, when it comes to website colour design, it has some disadvantages:

1. The lack of a readability test. Although the corresponding colours in a colour wheel are set to be opposite to one another, with the exception of few combinations, they are not guaranteed to maintain perfect contrast to each other, which may become difficult to read for the end-users.

2. It is time consuming. While creating a colour palette, a user may have to use a paper wheel chart or by a program [93] to pick the colours and their combinations manually.

3. There is also an issue with website colour similarity. Internet technologies have had a major impact on modern life, with the number of users from 2000 to 2012 increasing by a massive 566% [94]. To attract users to a new website, automatically choosing colours without the use of the colour wheel is difficult when seeking to avoid having colours similar to other websites. The colour wheel has a limited number of colours available which makes colour scheme duplication a problem for website developers.

2.3.2.2 **Using Images**

To overcome the drawbacks from manual colour wheel selection schemes, tools have been developed which allow for the automatic extraction of colours from a given image. As shown in figure 18, bright and dull colours from an image are selected automatically by these programs.

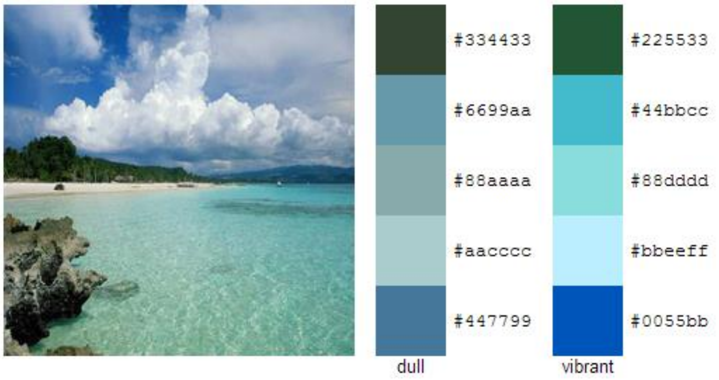


Figure 18. Creation of colour palette using an image[95] for extracting its bright and dull colours

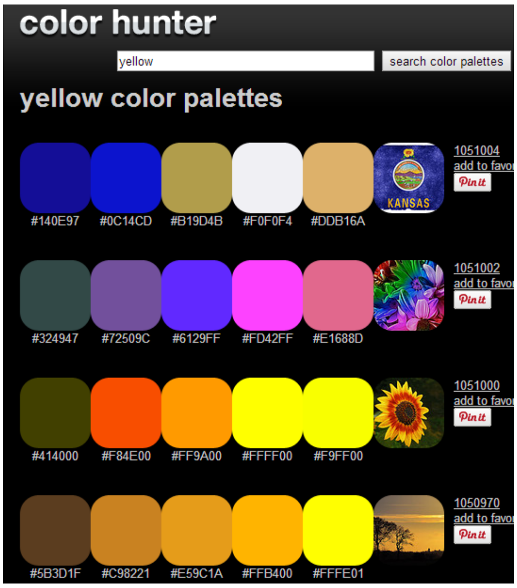
There are numerous applications which help users to build colour palettes based on an image, such as Kuler [96], TinEye Labs [97], Pictaculous [98], CSS Drive [99], Colour Palette Generator [95], Colour Hunter [100], and Colour Explorer [101], among others. In each tool, the methodology is similar, as explained in Table 4.

Steps	Procedure
1	Allows user to upload an image located in PC or through URL (Uniform Resource Locator)
2	Extracts vibrant and dull colours from an image
3	Allows user to hand pick extracted the colours for creating a palette
4	Saves colours directly into Hex format for using into the CSS file

Table 4. Common procedure observed in various colour palette builder tools

To facilitate more options to the user, tools like Kuler allow for the adjustment of colours, after the automatic extraction. This is to give more options to the user for selecting colours manually.

Colour Hunter is another tool that can build a colour palette based on various similar types of images that are available over the Internet whenever a particular colour is given by the user. For example, when a user selects yellow, then the tool will search for yellowish images over the internet and automatically creates a colour palette based on those images, as shown in figure 19.



color hunter

yellow

yellow color palettes

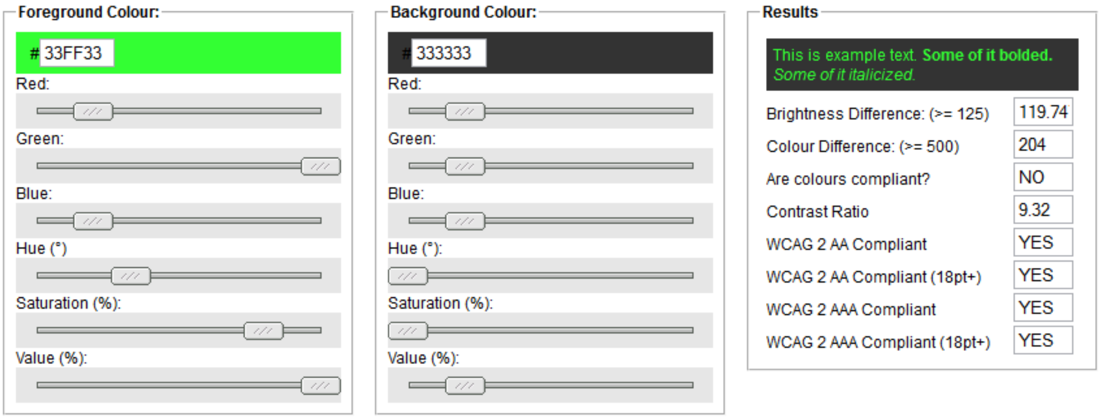
Figure 19. Automatic creation of colour palettes from images that contain yellow as a main colour

Such tools used for the automatic creation of colour palettes may satisfy the basic requirements of the user, which includes mixing colours, separate vibrant/dull colours and to create the whole colour palette (i.e. from an aesthetic point of view). But, it is not certain that the extracted colours can satisfy the readability test for the end-users. In this case, a user has to manually check the contrast levels between all the colours in order to make sure they are fully readable.

The most common drawback seen in all of the aforementioned tools is that they don't allow a methodical exploration of the space of possible colours and lack of aesthetic measures check. Suitable contrast levels are required for reading different sizes of text properly on a coloured background [102]. Based on the requirements for suitable contrast levels, the W3C offers a set of WCAG (Web Content Accessibility Guidelines) guidelines [103]: Contrast (minimum) and Contrast (enhancement), to help users find appropriate contrast levels between any two colours. The proposed contrast levels that help both users with normal vision and those with colour deficiency are detailed as follows:

1. Contrast (Minimum): The contrast level of smaller-scale text colour on a coloured background should be 4.5:1 and 3:1 respectively.

2. Contrast (Enhancement): The contrast level of larger-scale text colour on a coloured background should be 7:1 and 4.5:1 respectively.



Foreground Colour:

33FF33

Red:

Green:

Blue:

Hue (°)

Saturation (%):

Value (%):

Background Colour:

333333

Red:

Green:

Blue:

Hue (°):

Saturation (%):

Value (%):

Results

This is example text. **Some of it bolded.** *Some of it italicized.*

Brightness Difference: (>= 125)	119.74
Colour Difference: (>= 500)	204
Are colours compliant?	NO
Contrast Ratio	9.32
WCAG 2 AA Compliant	YES
WCAG 2 AA Compliant (18pt+)	YES
WCAG 2 AAA Compliant	YES
WCAG 2 AAA Compliant (18pt+)	YES

Figure 20. Snook colour test using W3C guidelines for evaluating colour combinations between two colours (green and black).

Based on contrast levels proposed by W3C, there are many tools available to users for finding the proper contrast between text and background colours. Tools include Snook [17], Juicy Studios [104], and The Paciello Group [105]. Most of these tools use a similar methodology, as summarized in Table 5.

Steps	Procedure
1	Allow user to select two different colours. One for the text and another for its background.
2	Calculate CCR ratio provided by W3C formula.
3	Show the results either pass or fail depending on CCR level limits between the two colours.
4	If the test result is passed, then the user can save them into the colour palette directly.
5	If the test result fails, then the user needs to adjust one or the other colour till the right contrast levels are achieved.

Table 5. Common procedure is followed by all W3C guidelines based tools.

Other than a suitable readability test, there are some other downsides to using these tools:

1. It is a time consuming process to work with these tools, because the user has to select the colours manually and test them one by one.

2. Users may get tired when matching the opposite colours, as the process requires tuning until the right CCR levels are found.

3. Users have to select, test and create the whole colour palette all by themselves.

2.3.3 Real-time colour scheme generators

There are some tools available to the end-users that allow changing the colour scheme of both websites and application interfaces interactively. In this case, users can simply select the available themes, or change colours manually according to their aesthetic preferences. A very limited number of websites offer this functionality, though those that do include Google mail, Yahoo mail, MSN mail, etc. Most operating systems will also allow a user to change the background colour, or set an image, as well as alter themes. Mobile applications also tend to provide the same facility. Any software that allows real-time changes to its colour schemes will typically not check for readability. This leads to a major drawback, as vision impaired individuals may find some of the colour combinations hard to read. However, there are some pre-defined colour themes available, mostly black and white combinations, for reading text on their interface. But, this is not a great option for the end-user as they still depend on the pre-made themes.

2.3.4 Related Information

Other than aforementioned tools for finding ways to create colour schemes, many researchers in the field of colour and evolutionary theory have been focused on investigating interactive tools for finding appropriate colour combinations and schemes for various digital artefacts which include websites, UI, images etc.

2.3.4.1 **Automatic colour scheme generation tools**

Guosheng et.al [106] in "*An interactive method for generating harmonious colour schemes*" has designed a harmonious colour scheme generation tool based on familial factors (using HSL colour space) and rhythmic spans (by identifying distance in colour space). This study approach is to change colour of any image into aesthetically harmonious colours by using their interactive tool. The author conducted focus group with 20 participants and found that feedback is more positive from novices in terms of achieving harmonious colour combinations than the professionals. To add more on aesthetic response to colour combinations from the literature, the authors of "*Aesthetic response to colour combinations: preference, harmony, and similarity* [107]" discuss three approaches to evaluating perpetual responses to colour combinations among people. These include aesthetic preference, harmony and figural colour by demystifying the distinct features in each of the approaches. The paper looks at three experiments, preference for colour pairs, colour harmony and its relation to preference, colour similarity and its relation to preference and harmony, preference for figural colours on background colours. The study compares their findings to existing colour theories in art such as Chevreul's theories [108] of harmony of analogous colours and harmony of contrastive colours, ecological valence theory (EVT) of single colour preferences, and fluency theory of aesthetic preference.

Meier et. al [109] used an IGA technique to construct a palette breeder. A palette breeder is used in their interactive palette tool (IPT) to help end-users bringing new colours (ideas) into the colour palette design. In each generation, ten colour palettes were generated based on a single colour palette i.e. selected by the end user during fitness evaluation test. In this study, fitness functions were not defined and also genetic operator's such as mutation is replaced with random equalizers and crossover with linear interpolation between two RGB values.

In "*A method of changing a colour scheme with kansei scales* [110]", authors proposed a system of changing colours of an image based on emotional feelings. Their system identifies index colour of any given image and then calculates its kansei value before applying any colour scheme to the original image. Authors showed an example of an original image changing into various kansei colour schemes such as hard, natural & warm and gay & bright by using their system.

In "*User preferred colour combination design using IGA"* [111], authors implemented an interactive tool to mix colours based on user preferences. This system contains one background colour with four foreground colours in each sample, where user is allowed to select a colour (object) in each sample with the aim of changing its properties in terms of darkness/lightness/vividness. During evaluation period, the selected colour is optimized through GA process giving solutions in newer generation. Termination of the system is reached only when the user is satisfied with the generated results. Authors conducted an experiment with ten participants to test their systems usability and gathered results through a questionnaire, which showed most of the users were satisfied with the results from their system.

In "*IGA for choosing suitable colours in UI* [112] & *Web-page colour modification for barrier-free colour vision with GA* [113]", authors implemented a system to optimize colour combinations process using GA for GUI's. Both, the end user fitness evaluation (IGA) and aesthetic fitness measures techniques were used during evaluation period. The main purposes of the aesthetic measures used in this paper are to find contrast levels (CCR) and to measure the distance in colour space (by using CIELab [114]) between any two colours. With this approach, the aim is to optimize a colour palette based on user preferences by maintaining both contrast levels and chromatic settings. Results of six evolved colours and the fitness graph were shown after running thousand numbers of generations which were guided by both end user and aesthetic measures.

Giovanni designed a system called colour harmoniser (CH), to optimize colour combinations for UI's by satisfying both user preferences and aesthetic measures[115]. CH uses IGA technique to optimize colour combinations based on user personalization. Four types of fitness functions were used to check colour strength balance, wireframe alignment, readability and distinguishability between colours. All four fitness scores are normalized into one final fitness function to evaluate colour combinations during evaluation phase. Giovanni conducted an experiment to test the CH quality and usability with more than three hundred participants asking them to create two colour schemes for an UI, by using CH and another and with hand-picked colours. Based on the results obtained, with help of another 73 participants, author conducted a focus group and found that CH generated colour themes have higher rating than traditional way of building colour schemes, completion of time, relative difficultness, harmonious colour schemes generations and overall usability.

2.3.4.2 **Use of colours and their combinations in websites**

Papachristos, Tselios & Avouris [116] in "*Bayesian modelling of colour's usage impact to web credibility*" discuss the role of colour in web design in eliciting perceived aesthetic and emotional value among consumers or website visitors. The researchers developed Emotional Colour Model (ECM) by using Artificial Intelligence (AI) techniques that can suggest appropriate colour combinational schemes to any type of the website designs. The adapted model is used to examine colour usage, in the frame of interior space design. The authors undertook two empirical studies to identify the quantitative relations between emotional dimensions and colour usage in a specific layout using a Bayesian networks approach correlating colour models of websites to values that are attributed to its users. The authors find that their results provide justification for previous research in colour usage. The authors find that several attributes seem to have more usefulness than others.

The paper "*Predicting Users' First Impressions of Website Aesthetics with a Quantification of Perceived Visual Complexity and Colourfulness* [117]" examines users' first impressions of websites with the authors seeking to develop a method which can predict design's aesthetic appeal among consumers by developing quantitative models for predicting users' first impression of aesthetic qualities. The authors conduct experiments from volunteers to collect colourfulness, complexity and visual appeal ratings. Their findings show that colourfulness and complexity explain almost half of variations in visual appeal ratings whereas visual complexity has a significant impact for users' first impressions of appeal at first sight. The researchers also find that demographic variables (age, gender, education) do have an effect on first impression of websites.

In "*Exciting red and competent blue: the importance of colour in marketing* [118]*"* the article discusses the impact of colour in the marketing industry in attracting and shaping consumer perceptions of the product. The authors focus on the relationship between colour and brand perceptual measures in a series of four studies; mapping of ten colours onto brand personality dimensions, saturation and value, uses of colour to alter brand personality and purchase intent and impact of brand logo shape and colour on brand personality, familiarity, and likability. The findings support the relationship between colour and brand personality, influenced by colour's meaning. The authors conclude by giving theoretical and managerial implications of their findings.

In the paper "*The influence of website category on aesthetic preferences* [119]", Papachristos and Avouris conducted three evaluation studies involving website designs from three distinct domains, these are; tourism, healthcare and web design business domains which differ in characteristics and purpose. In all the domains the most dominant factor was visual appeal with differences observed between the three domains on what constitutes an appealing website. Healthcare (perceived usability and credibility), tourism (mostly graphics, vivid colours, large images) and web design business (visual appeal and novelty). The findings show that different design aspects play a significant role in designing specific websites for specific domains or sectors. The authors recommend that web designers should not use generic questionnaires in designing websites as specific attributes for that specific domain could be ignored.

2.3.4.3 **Surveys identifying proper colour combinations**

There were a number of surveys conducted by many researchers in order to find the proper colour combinations that mostly satisfy human aesthetics while reading text on a coloured background. Some of papers are summarized as follows:

2.3.4.3.1 Gender perceptions on colours

The paper focus is on the hedonic dimensions of HCI and their relevance to usability. Coursaris, Swierenga and Watrall [120] in "*Effects of colour and gender on the perceived attractiveness of websites*" cite gender differences on perceptions of the web design based on the attractiveness, usability, and the consequent affective state of satisfaction. The objective of the paper is to explore the effects of colour and gender on the perceived attractiveness of websites. Hedonics implies the factors in the web design which stimulate pleasure. The authors hypothesize that there will be differences between men and women in relation to their perceptions of website attractiveness for each colour combination. Adopting a 2 x 2 research design, the authors find that colour combinations have an impact on website attractiveness whereas gender has no significant impact on web attractiveness.

2.3.4.3.2 Readability tests

The paper focuses on the readability of websites based on several attributes which include the foreground/background, colour combinations, font types and word styles. Hill [121] in "*Readability of Websites with Various Foreground/Background Colour Combinations, Font Types and Word Styles*" introduces the concept of Visual Display Terminal (VDT) designs legibility and readability and its influence on communication. The experiment involved 43 participants who were exposed to a nation-wide internet survey which incorporated 30 text stimuli and were presented in each colour combinations where the 30 text pages ranged in length from 130 to 150 words. The findings show that there were significant effects and interactions for font type, word style, and colour combination, contrast was also found to affect legibility.

The article focuses on the affective effect of colour contrast between text and the background when humans read the text on a LED display based on psychological and physiological responses. Lee and Hyeon-Jeong [122] conducted two experiments in "*The Effect of Color Contrast between Text and Background on Human Comfort*", to investigate the emotional response, especially the level of comfort to varying brightness differences between the text and the background and to investigate the emotional response about various hue differences between the text and the background with the same brightness difference. The authors found that white background and 60% grayscale text combination is the best for reading context. The authors further conclude that brightness difference between text and background is more influential to people than hue difference. The paper recommends that designers should pay attention to differences in hue and also in brightness as they were found to affect the physiological well-being of the user.

2.3.4.3.3 E-commerce

Bagchi and Cheema [123] explore the effect of red backgrounds on willingness-to-pay in auctions and negotiations. The author hypothesizes that red colour will elicit higher willingness to pay at auctions but would lower willingness-to-pay in negotiations and individuals exposed to red will make lower offers compared to those exposed to colour blue. The author conducts three studies; colour affects aggressive bidding on eBay, effect of colour on willingness-to-pay in negotiations and fixed price comparisons and process measures. The authors find that red colour arouses aggression and aggression mediates the effect of colour on willingness-to-pay. Further, the study finds that the effect of colour on purchase likelihood is similar across negotiation and fixed price conditions.

The paper "*The Influence of E-commerce Website Colours on Usability*" [124] investigates the effects of the colours used in e-commerce websites on consumers' behavior in relation to website usability. The author adopts colour components of hue, brightness and saturation and their assumed influence on predicting consumer behaviour and intentions itemized as memorization and buying intention. The author adopts qualitative approach (semi-structured interviews) to gather information from consumers in regard to e-commerce websites and quantitative approach (questionnaires) using a 4 x 2 experiment design using two mediating variables (stimulation and negative mood). The paper finds that effects of the colours used on e-commerce websites have an effect on consumer retention of information and buying intention.

2.3.4.3.4 Multicultural colour differences

The paper "*Colour and Brand Design for Multicultural Packaging*" looks at the concept of multicultural packaging approach in graphic communication on designs and branding. Valillez [125] argues that multicultural packaging rationale is to be able to effectively communicate to a diverse population group about a certain product to influence consumption. The author adopts historical research and content analysis as research methods. The paper presents models of brand personality dimensions for America, Japan and Spain including facets that describe each of the brand personality dimensions. The study finds that there is at least one culture-specific dimension. For the American culture (ruggedness), Japanese culture (peacefulness), Spanish culture (passion as well as peacefulness). The author suggests that companies need to incorporate consumer cultural perceptions in designing brand identity to promote global consumption of a company's product.

2.3.5 Summary

From mixing colours to applying colour schemes, designers have to depend on manual time consuming processes and tools that are not user friendly. To help end-users in the creation of an automatic process for updating the colours of a website design, images and GUI's, many researchers have investigated EC driven palette generation techniques and developed tools that can partially satisfy the need. As an extension in the field of colour theory, this research develops a prototype of an interactive colour scheme generation tool that is capable of generating a complete set of colour palette for a website design by allowing both normal and vision impaired individuals to read with greater ease and also capable of generating aesthetically pleasing colour combinations during the evolution process with the help of three main aesthetic measures from W3C.

2.3.6 Conclusion

Based on the existing theoretical (related information) and experimental (software) methods currently available for both terrain and colour scheme generation processes, the research aim was to address the following drawbacks observed in the literature review. This will be achieved by developing an application, using evolutionary algorithmic techniques, that does not require much human input to achieve desired outputs:

1. The current terrain generation methods available often require a huge number of manual inputs from the user.
2. The currently available tools can increase user fatigue due to the time it takes to familiarise oneself with the techniques involved in terrain generation software and to create desired sceneries.
3. The research methods for terrain generation are mostly concentrated on developing the virtual reality appearance of the terrains rather than the usability of the tools. This

means users are still required to adjust a huge number of parameters in order to achieve the desired outputs.

4. Finding a proper colour scheme for an application is still un-resolved as most of the current colour scheme application tools are dependent on a manual process for identifying the colour scheme.
5. Colour wheel selection is helpful only for a fixed number of colour combinations that are present on the wheel. Otherwise, users have to prepare colours manually for creating a colour scheme, which could lead to user fatigue or produce imbalanced aesthetics measures.
6. An automatic colour scheme generator is not available for creating interactive colour schemes, which could be beneficial in many fields such as art, climate change visualisation, day and night colour schemes, etc.
7. There are not that many research methods or tools available to the end-users to generate an interactive colour scheme based on user preferences.
8. The available semi-automatic tools that are capable of producing opposite colours are user depended, where the user has to manipulate mixing colours till satisfactory results are achieved. When there are many colours in a colour scheme to generate, then finding the remaining colour combinations can lead to user fatigue.
9. Most of the currently available tools for generating colour schemes are failing an aesthetic measures test, which could affect mostly colour impaired individuals such as readability, identity and aesthetics.
10. As observed in the literature review, many researchers have attempted to find proper colour combinations between background and foreground colours to improve readability. Out of $(1.6 * \ 10^7)^n$ of colours, only a small number of colour combinations (less than 20) were tested so far.

3 Design & Implementation

3.1 Introduction

In this chapter, the design and implementation of the evolutionary processes for landscape design and website colour schemes are discussed. At first the EC framework was designed then implemented, with GAs methods and tools for executing the evolutionary processes. The processes involved in developing the landscape design and website colour schemes are explained with examples. The architectural design and use of network render farms for the evolution of landscape designs are explained. Additional tools that are implemented within the framework to help end-users during the evolutionary process are discussed.

3.2 Framework

The EC framework was built by using the C# programming language and the Microsoft .NET (dot net) framework in both web and windows forms. One of the main objectives of this framework is to design and develop a prototype to carry out the evolutionary process for various searches based digital artefact problems. During the development phase, the following requirements are taken into account:

- To develop GUI’s for the end-user that can perform both GA and IGA techniques for the evolution of landscape design and website colour schemes.

- To develop tools that give manual control over some features that are involved in the evolutionary process, such as changing probability rates of crossover & mutation, adding and removing aesthetic fitness measures, ranking samples etc.

- To develop tools that help the end-user have control over the features that are not involved in the evolutionary process, such as render settings, image sizes, inserting 3D models, etc.

- To develop a local network render farm for speeding up the whole evolutionary process.

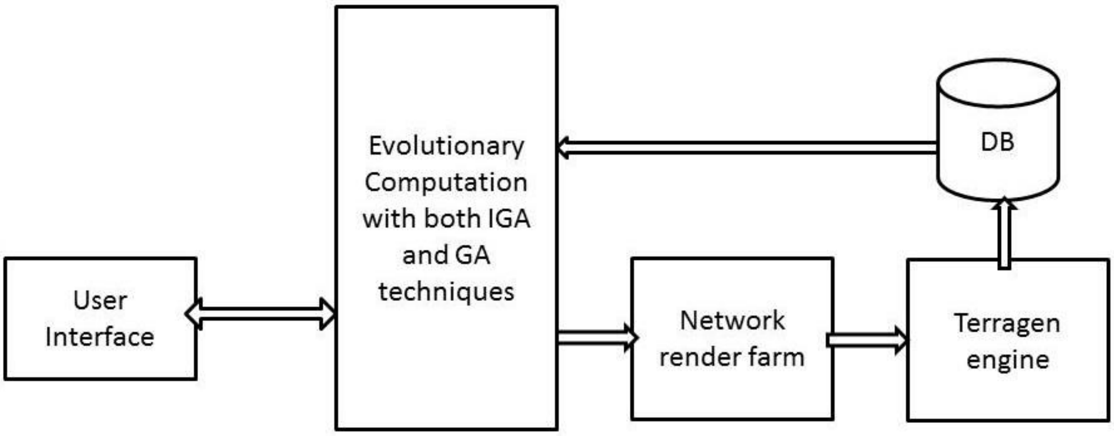


Figure 21. System Architecture design for the evolution of Landscape designs

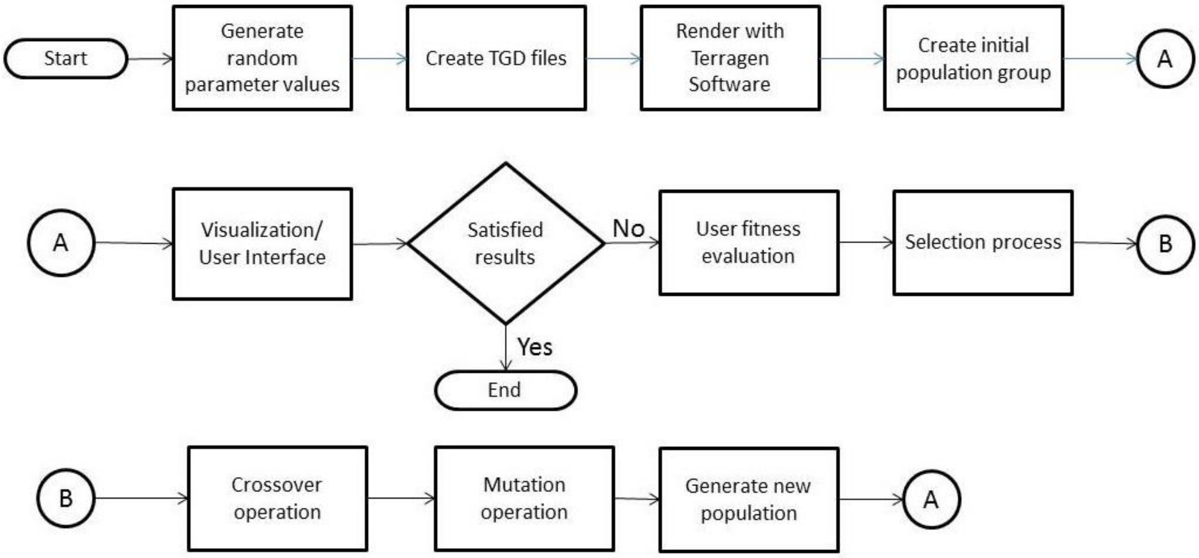


Figure 22. Flowchart diagram for the evolution of landscape designs using IGA technique

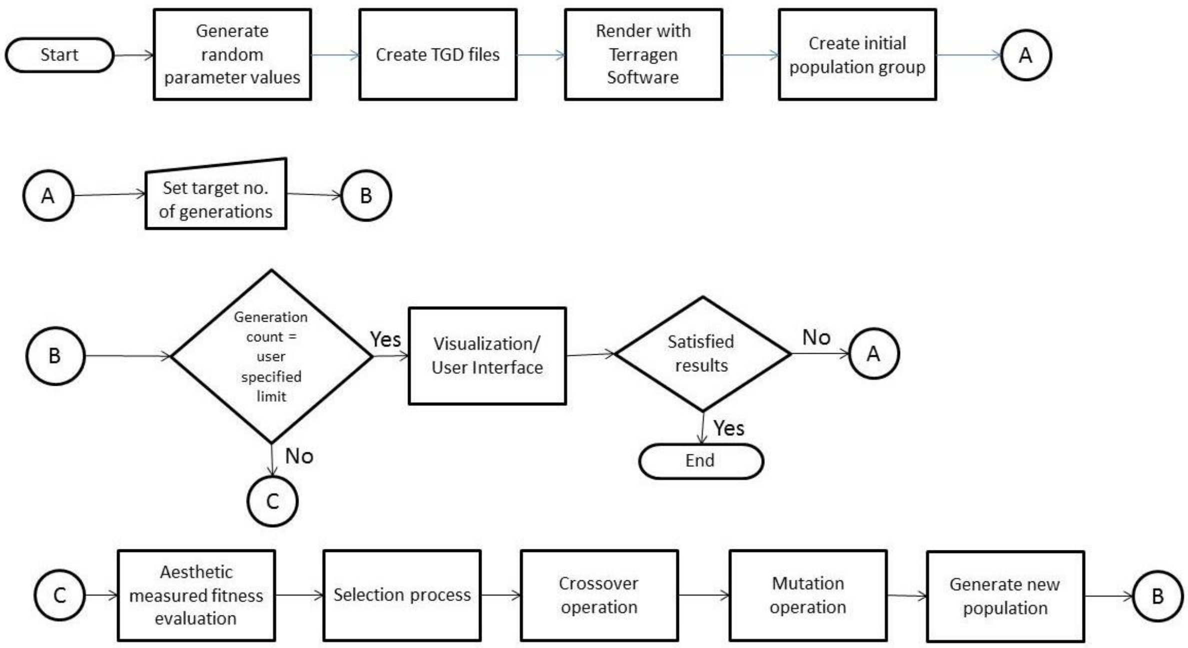
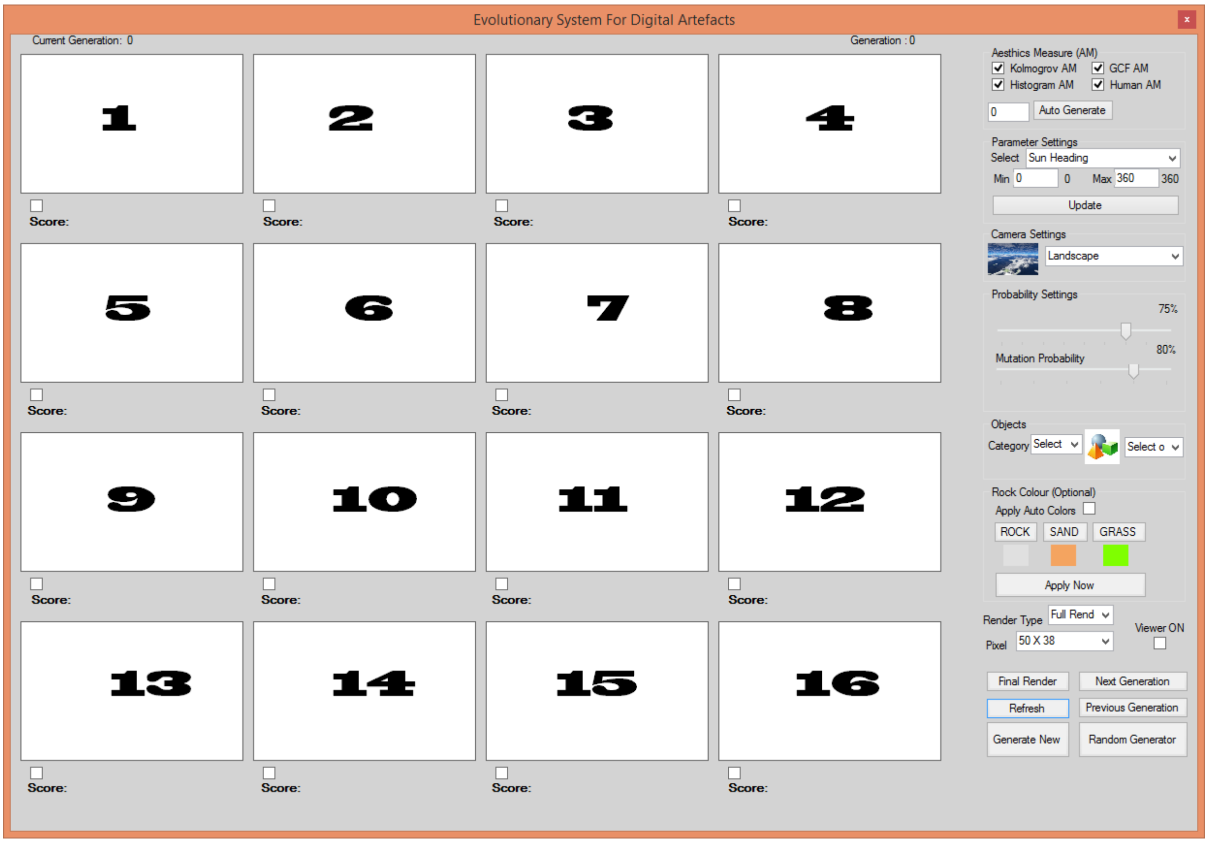

Start
Generate random parameter values
Create TGD files
Render with Terragen Software
Create initial population group
A
A
Set target no. of generations
B
B
Generation count = user specified limit
Yes
Visualization/ User Interface
Satisfied results
No
A
Yes
End
No
C
C
Aesthetic measured fitness evaluation
Selection process
Crossover operation
Mutation operation
Generate new population
B

Figure 23. Flowchart diagram for the evolution of landscape designs by using aesthetic measure fitness evaluation technique

All the tools are integrated in a single Microsoft Windows format (WinForm) as shown in figure 24. This framework is designed to run 16 numbers of samples for the evolution of landscape designs and 12 numbers of samples for the evolution of colour schemes.


Evolutionary System For Digital Artefacts

Current Generation: 0

Generation : 0

Aesthics Measure (AM)

☑ Kolmogrov AM ☑ GCF AM

☑ Histogram AM ☑ Human AM

0

Parameter Settings

Select: Sun Heading

Min 0 0 Max 360 360

Camera Settings: Landscape

Probability Settings 75%

Mutation Probability 80%

Objects

Category: Select, Select o

Rock Colour (Optional)

Apply Auto Colors □

Render Type: Full Rend

Pixel: 50 X 38

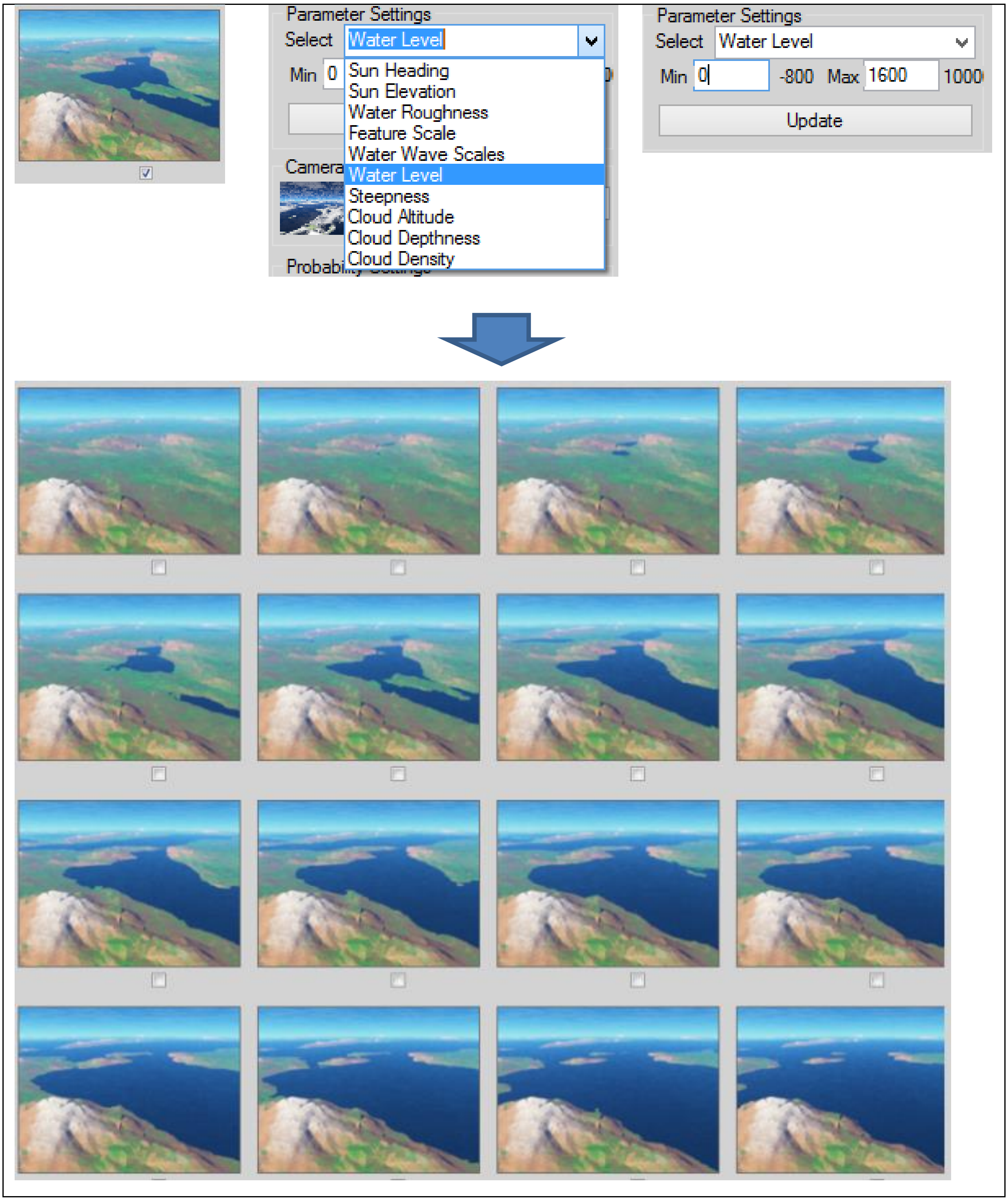
Viewer ON □

Figure 24. GUI for evolutionary system for digital artefacts with 16 samples.

Additional tools included in this framework are; parameter settings, generation histories, image size adjustments, view point adjustments, texture colours, crossover and mutation probability adjustments, 3D models insertions, adding or removing aesthetic measures, locking favourite colours, and uploading images into website templates.

3.2.1 Parameter settings

Users can manually change the range of a particular parameter to see the effect on each individual in the next generation. Depending on the minimum and maximum values entered by the end-user, the system will perform the rest of the manipulations and render settings before processing the end results. For example, if the user wants to see different levels of water ranging from 0 to 1600 for the same scenery, then the system will distribute the values equally on each individual starting with the value 0 and ending with the value 1600 (0, 100, 200, 300,…, 1600) and then render all 16 landscape designs with their appropriate water levels as shown in the figure 25.



Parameter Settings

Select Water Level

Min 0 -800 Max 1600 1000

Figure 25. Examples of water level increasing of selected scenery from level 0 to 1600.

3.2.2 Generation Histories

Generation histories are directly stored into the DB each time the evolutionary process is performed. This is designed to help the end-user re-visit each previous generation and, if desired, re-start the evolutionary process from the chosen generation. This also means that the end-user can load a landscape that has been through the process to investigate the evolution of the landscape design by simply using the two buttons: *Next Generation* and *Previous Generation* that are in the GUI, as shown in the figure 26.

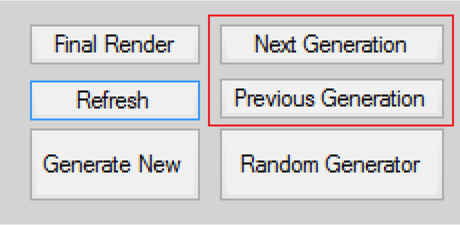


Figure 26. Browsing generation histories using next and previous generation buttons.

3.2.3 Image size adjustment

This editor allows the end-user to change both the default size of an image and the render settings in the system. To obtain quicker render timings between generations, the user can simply select a small scaled image size and a quick render option. If the image scale is set too large together with the full render option, then the processing time for rendering an image will increase causing the entire process to be delayed. However, these settings will produce the highest resolution landscape designs. The following Table 6 shows difference between image size, render type and the quality of the rendered image.

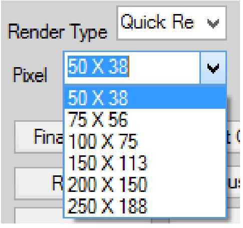
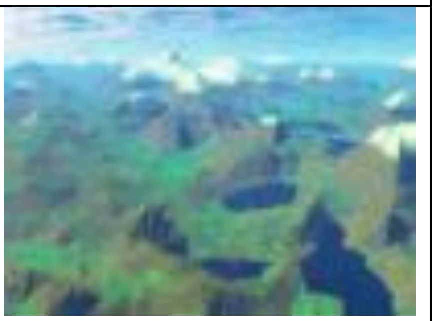
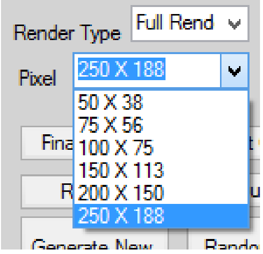
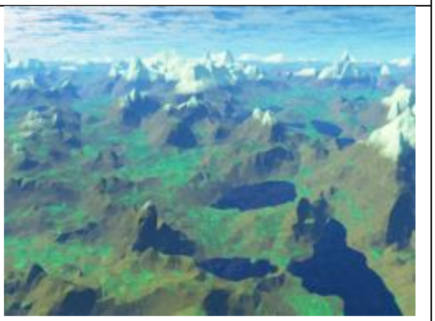
Image size	Render type	Render processing time	Resolution
 Render Type: Quick Re Pixel: 50 X 38 50 X 38 75 X 56 100 X 75 150 X 113 200 X 150 250 X 188	Quick	7 seconds	
 Render Type: Full Rend Pixel: 250 X 188 50 X 38 75 X 56 100 X 75 150 X 113 200 X 150 250 X 188	Full	27 seconds	

Table 6. The resulting LOD and render time when different size of image selection is made.

3.2.4 View point adjustment

By default, the camera position is kept at a constant, i.e. at a fixed elevation point and at set rotational (horizontal and vertical) directions. Using this tool, the user can change the viewpoint position, simply by selecting the pre-defined camera settings from an easily accessible dropdown menu. For example, figure 27 shows the results of rendered sceneries when the camera angle is set in globe mode.

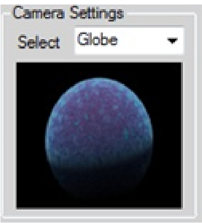
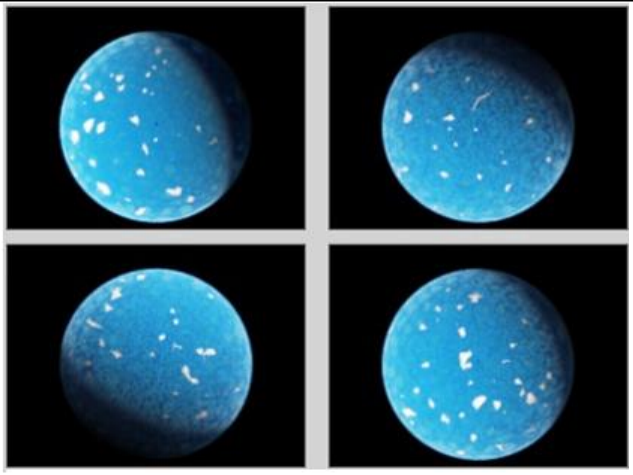
Camera Settings	Results of the samples
 Camera Settings Select Globe	

Figure 27. Generation of individuals when camera angle is set to full globe mode.

3.2.5 Manual Colours

By default, the system identifies texture colours from the best fitted individuals (parents) during the selection phase, combines their colours during the reproduction process, and then applies the resulting colours to the newly born offspring. However, when the texture colours are not considered to be important during the evolution of the landscape design, the end-user can simply overrule the *autoColour* generation tool by manually selecting the individual colours for grass, sand, and rock using the colour picker tool. An example of the changing colours on the same landscape design is shown in Table 7.

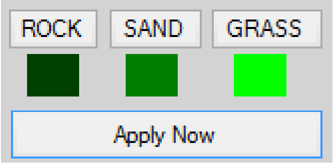
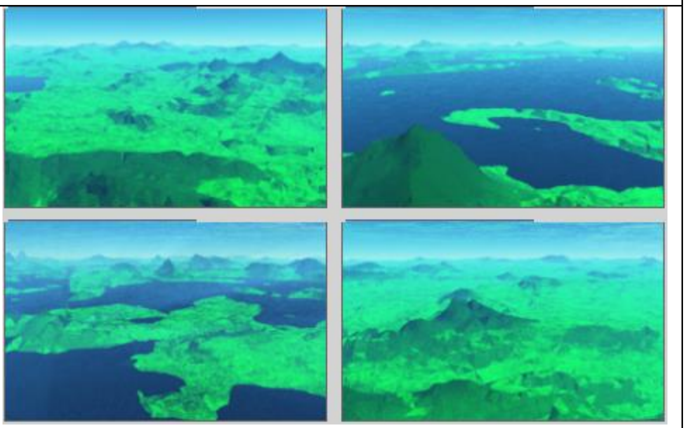
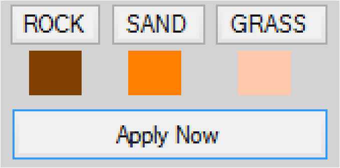
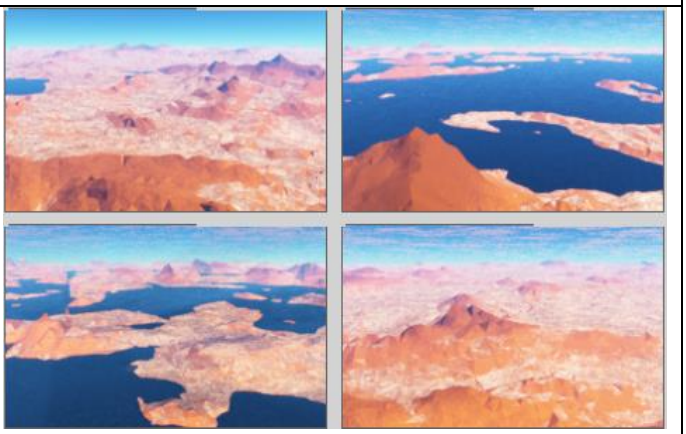
Selecting manual colours	Results on the samples
	
	

Table 7. Applying manually selected colours over the landscape designs.

3.2.6 3D Model Insertion

This is a tool that will allow the end-user to insert 3D models created with Terragen into the evolved/rendered landscape. Initially, a set of 3D models is available in the framework where the user can select a model using the dropdown menu. The position of the model is auto adjusted by the system when inserted. For example, when a 3D model of a ship is inserted, the system will check the water level of that particular landscape design then adjust the elevation point of the ship model to the correct height in order to give an impression of it floating in the water. The same applies when an aeroplane model is inserted into the landscape design, the camera angle and elevation point of that model are adjusted automatically to give a clear view of the aeroplane flying over the generated landscape. The insertion of models, ship and aeroplane, are visualized in Table 8.

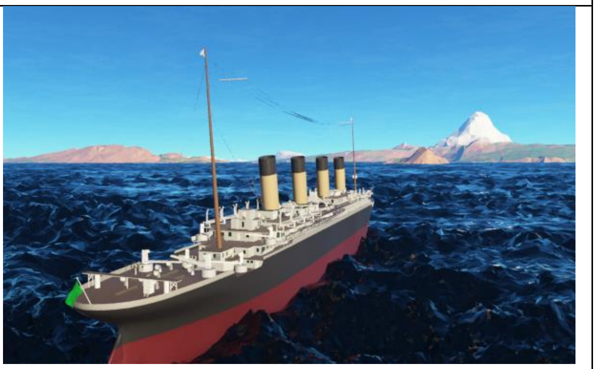
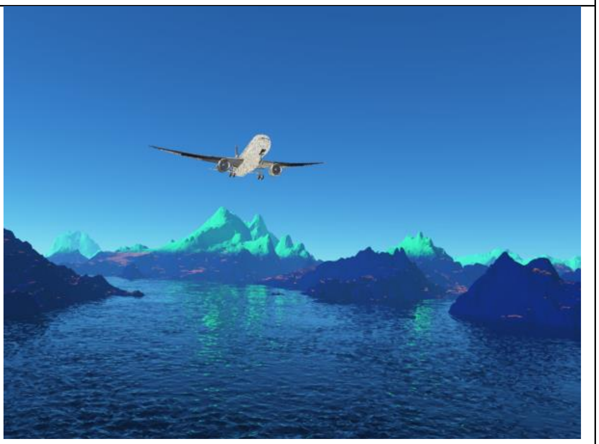
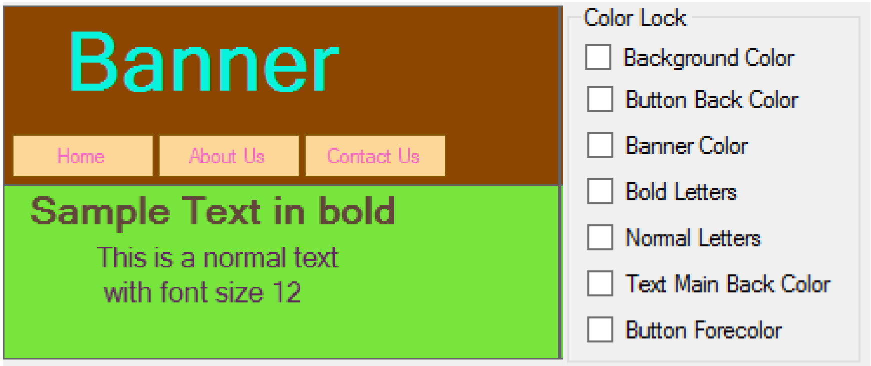
3D models	Results on the samples
Ship	
Aeroplane	

Table 8. Placement of 3D models is automatically adjusted depending on the landscape designs.

3.2.7 Lock colours

This option is designed to allow the end-user to lock and save their favourite colours during the evolutionary process for; banner, banner-background, buttons, button-texts, main section, bold, and normal font text. This locking of colours is a necessary tool for the end-user while using IGA technique during the evolutionary process of website colour schemes. When aesthetic measures are guiding the evolutionary process, then the framework itself will lock and save the colours as required.



Banner

Home | About Us | Contact Us

Sample Text in bold

This is a normal text
with font size 12

Color Lock

□ Background Color
□ Button Back Color
□ Banner Color
□ Bold Letters
□ Normal Letters
□ Text Main Back Color
□ Button Forecolor

Figure 28. Saving colours interface with check boxes

3.2.8 Add image banner

As part of the process for the evolution of colour schemes, the end-user needs to input their favourite colour before the framework will evolve the remaining colours in a palette. Alternatively, by using this tool, the user can simply upload an image and the framework will extract the most vibrant colour from the image and evolve the remaining colours. An example is shown in Table 9, where use of an image input has generated the appropriate colour scheme for a simple website design.

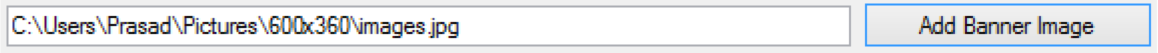
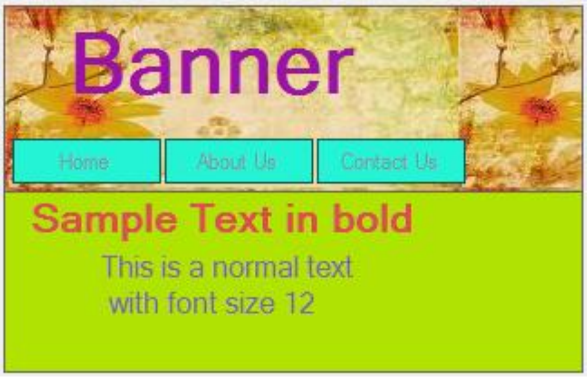
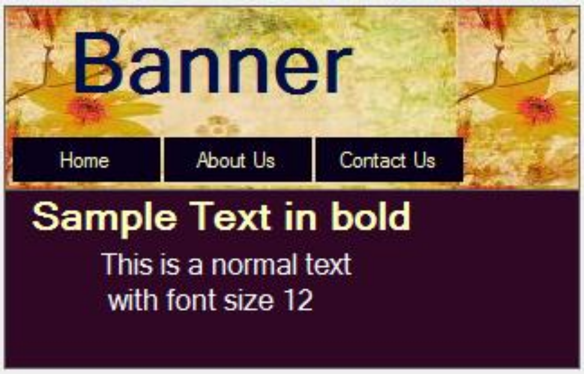
Randomly generated colour scheme	Evolution of colours based on image
 C:\Users\Prasad\Pictures\600x360\images.jpg	
 Sample Text in bold This is a normal text with font size 12	 Sample Text in bold This is a normal text with font size 12

Table 9. Website template on the left side shows randomly generated colour scheme and the website template on the right side shows the colour scheme generated based on image colours.

3.2.9 Network Render Farm

A render farm is several computers working together in a cluster; in this case the render farm was built to render computer-generated imagery. By default, each landscape design in this research is rendered with a fixed size of 200 X 150 pixels. The rendering time taken to convert a single TGD file into a complete image is approximately 20 seconds, when ran on a single machine (Intel Core i7 @ 4 X 2.90GHz, RAM – 10GB, OS – Windows64Bit). This indicates that for each generation, the time taken to render 16 landscape designs is 5 minutes and 33 seconds. Therefore, if the end result requires 25 generations to run, then the time taken to perform the complete process is more than or equal to 2 hours.

To help reduce the time taken, both between the generations and the whole process, a render farm solution will provide the desired reduction. But, there are only relatively few render farms available online, such as SquidNet [126] and deadline [127] , to process TGD files into images. Also, the drawbacks of online render farms are cost and response time. To resolve this problem, this research developed a local render farm comprising of a single server and ten client machines using WCF, Microsoft Windows service, and Windows installer programs. The system's architectural design is shown in figure 29. This now makes it possible to reduce the rendering time taken between each generation to 32 seconds, and to complete the whole process requiring 25 generations to less than or equal to 13 minutes.

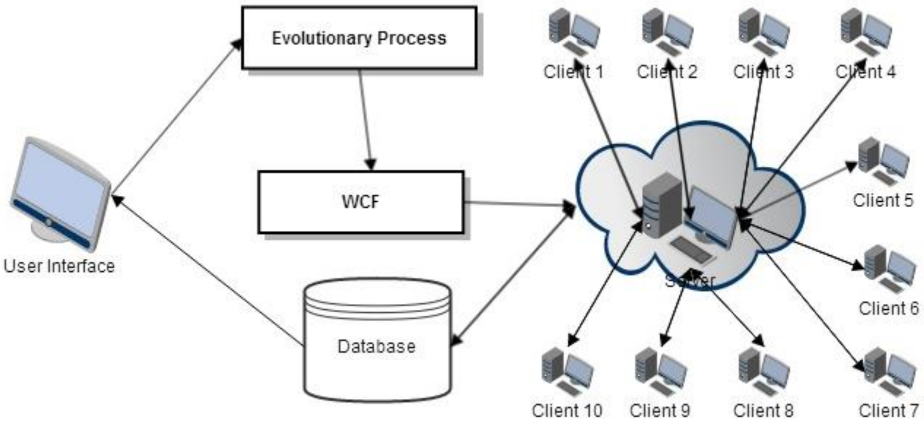


Figure 29. Network Render farm architecture design

The complete process is carried out by following these steps:

1. A TGD file is divided into ten parts and sent to the client machines to render each of the parts into images. Each sub-divided TGD file carries information for re-joining them into a single image later in the process.

2. The installed Windows service on each client machine then executes the Terragen render engine when a part of the TGD file is received from the server.

3. When the rendering process is completed on each client machine, the processed images are saved directly to a respiratory folder located on the server.

4. Once the server has received all ten parts of the first rendered image, an image stitching program is executed to join the parts back into a one full image by using the embedded (re-joining) information.

5. The server then starts the process for the second TGD by following step 1, step 2, step 3 and step 4. This is repeated until all 16 TGD files are converted into 16 landscape designs.

3.3 Evolving Landscape designs

3.3.1 Genome Representation

In the field of evolutionary theory, information of an individual is fed into the system in the form of a genome string. The genome string contains features of that individual that identifies their uniqueness during the evaluation phase. In this research, for the evolution of landscape design, parameters that highlight an individual are selected for genetic operation and later added to the remaining parameters to form a complete genome string as shown in figure 30.

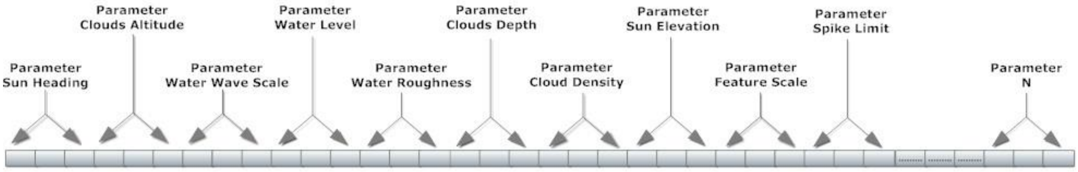


Figure 30. Genome string containing all features of a Landscape design

A landscape design generated by Terragen contains numerous parameters to visualise its different properties. For initial investigation, 13 parameters are selected and processed through the genetic operations. Each parameter can be represented by a floating number or a real number within the Terragen software. Each character value is converted to binary for the genetic operations. The 13 parameters processed are:

1. Feature scale – to change size and height of a terrain
2. Spike limit – to adjust the roughness on the surface of the terrains
3. Sun directions – to visualise North, East, West and South directions
4. Sun elevation – to change the time of a day
5. Cloud altitude – to adjust altitude level of clouds
6. Cloud density – to adjust the density levels of clouds
7. Cloud depth – to adjust the thickness of the clouds
8. Water level – to adjust water tide levels

9. Water roughness – to adjust the roughness of water
10. Water waves – to increase or decrease water waves
11. Grass texture– to change the texture colour of grass
12. Sand texture – to change the texture colour of sand
13. Rock texture – to change the texture colour of rocks

3.3.1.1 **Feature scale**

The terrain is the key feature that defines any landscape design. In Terragen the terrain is defined as feature scale. This feature is chosen in the evolutionary process to see the variations in elevation, slope, and orientation of the terrains. For scaling the size and height of a terrain, Terragen has assigned an integer value as their numerical representation ranging from 0 to 1X10^6, where value 0 indicates flatter and smoother fields and higher value for mountainous features. The range (0, 1X10^6) is brought down to a binary range (0, 255) for performing genetic operations and reverts back to the original range when rendered into images by using Equation 2 and Equation 3 respectively. An example of terrain feature at different values of feature scale is shown in figure 31.

$$Convert\_To\_Bin_{value} = \frac{Input_{value} - Parameter_{min}}{Ratio} \tag{2}$$

$$Convert\_To\_Parameter_{value} = Parameter_{min} + \left(Input_{value} * Ratio\right) \tag{3}$$

Where, $Ratio = \frac{Parameter_{max} - Parameter_{min}}{Binary\_bit_{max} - Binary\_bit_{min}}$

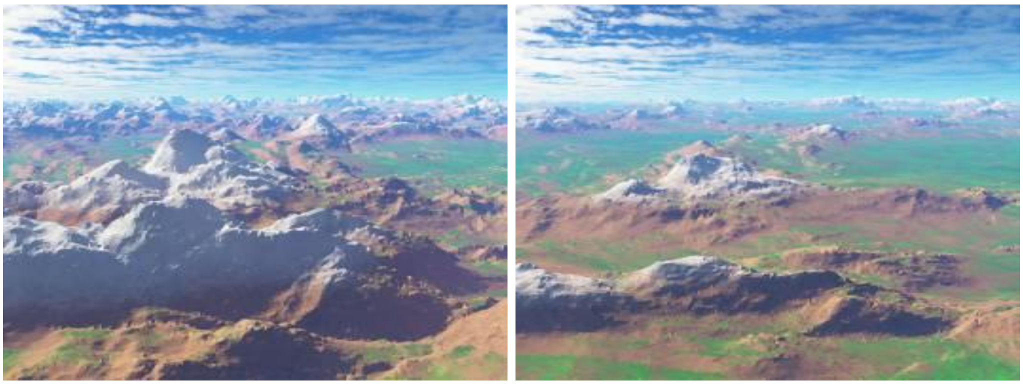


Figure 31. Decreasing feature scale of terrains from a higher level (Left) to a lower level (Right).

3.3.1.2 **Spike limit**

This parameter is chosen to bring smoothness, roughness, steeper and rockier mountain shapes onto the terrains. Its values range from 0 to 1, where 0 is for a smoother surface and the higher the values the spikier the terrains look. The original range of this parameter (0, 1) is mapped to (0, 255) to make it an 8-bit binary range during the evolution process, by using Equation 2, and then reverted to its original range after the GA operations are performed by using Equation 3. The effect of the terrain spike limit value on terrain is visualised in figure 32.

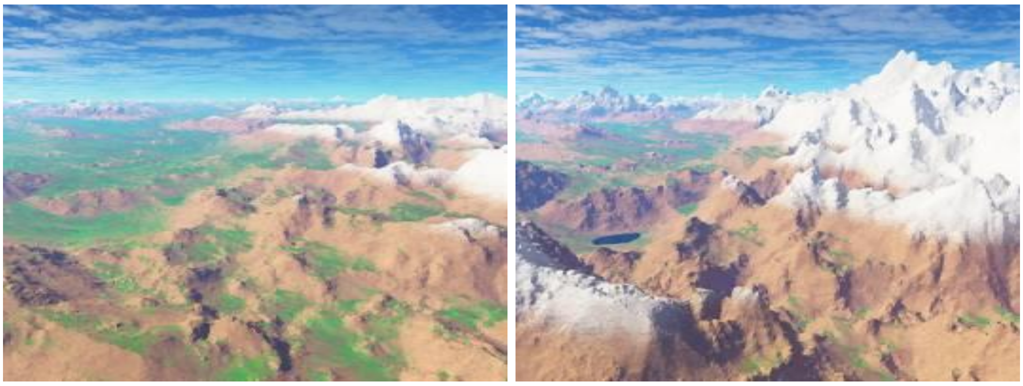


Figure 32. Effect of displacement spike limit value on the terrains of the same scenery when decreased (Left) and increased (Right).

To increase height and spikiness of the terrains at the same time, a user has to tune both the feature scale and spike limit parameters simultaneously until the desired results are achieved. Instead, in this research, GA finds the proper balance between these two parameters automatically, adjusting them according to the desired output; either given by a user or chosen by aesthetic measures during the evolutionary process.

3.3.1.3 **Sun Direction**

This parameter is used to change the direction of the Sun. This assists in managing the shadows of the terrain and other objects rendered in a landscape design. This parameter's values range from 0 to 360, which represent degrees of a compass. In Terragen, when the sun direction parameter is set at 0° it indicates that the sun is pointing towards the South direction, 45° towards North-East, 90° towards the East, and so on. The range (0, 360) is mapped to (0, 255) for performing GA operations. As seen in figure 33, changing the Sun direction on the same scenery brings significant differences in lighting, shadows, texture colours etc.

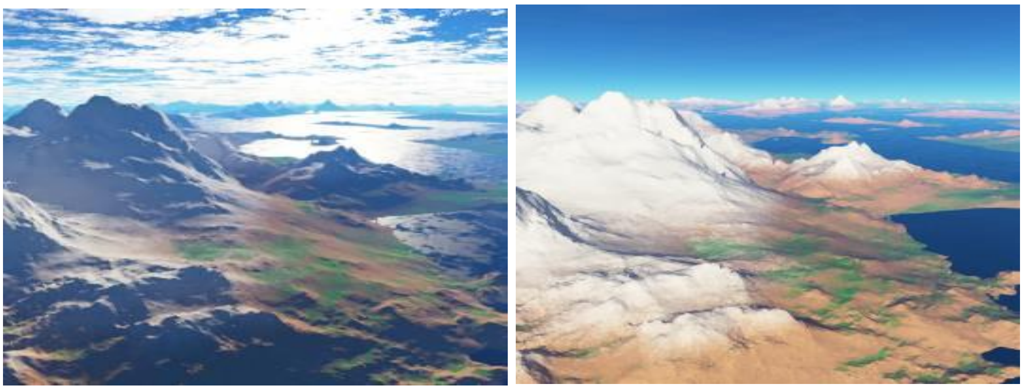


Figure 33. (Left) Screen shots of scenery when the sun is facing South and (Right) when facing North (with user viewpoint looking North).

3.3.1.4 **Sun Elevation**

The Parameter, Sun elevation, defines the angle of the Sun above the horizontal plane and this gives the effect of a particular time of a day of the scenery created by using Terragen. Using this parameter, it would be possible to create sunrise, sunset, daytime, night-time sceneries. Its value range is set from -90 to 90 and is represented in degrees format. Thus -90° indicates the Sun is perpendicular to the horizontal plane and below it, i.e. midnight and 90° is perpendicular and above, i.e. midday. The range (-90, 90) is mapped to (0, 255) for performing GA operations. In figure 34, an example is shown of the same scenery with the Sun at different elevation angles.

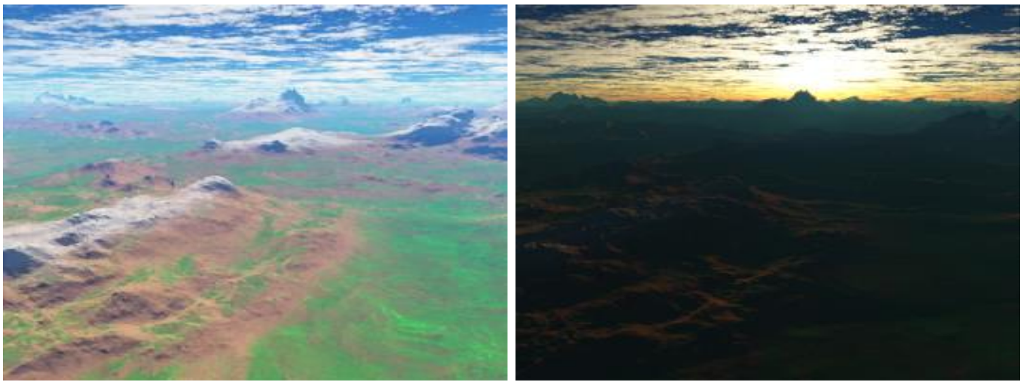


Figure 34. Same scenery rendered with different angles of the Sun. A Sun angle of 45 degrees (Left) and 8 degrees (Right) (looking towards the Sun).

Both parameters of the Sun, direction and elevation, need tuning while generating any landscape design in Terragen. For example, to create a scenery around sunrise, the Sun direction parameter needs to set to around the East direction (90°) and Sun elevation parameter angle needs to set from -6 to 6 degrees; for scenery around sunset, the Sun direction parameter needs to set to around the West direction (270°) and sun elevation parameter needs to set from 6 to -6 degrees. The end-user should also be aware that changing the Sun parameter values could also have an effect on other parameters such as lighting, textures colours, shadows, etc. In this research, GA manages to tune both parameters simultaneously to modify the outputs.

3.3.1.5 **Cloud Altitude**

The elevation (height) of clouds is controlled by the cloud altitude parameter for any scenery or landscape design that is created in Terragen. Using this parameter, distance between ground and clouds can be decreased or increased. Its values, equating to a measurement in feet, range from 0 to 20000, where 0 indicates ground level, i.e. fog and at 20000 high altitudes for clouds, e.g. Cirrus. This parameter can be used to change the climatic conditions of the same scenery with different effects, i.e. a foggy atmosphere with less visibility into a clear visibility, as shown in figure 35. Its range (0, 20000) is mapped to (0, 255) for performing GA operations.

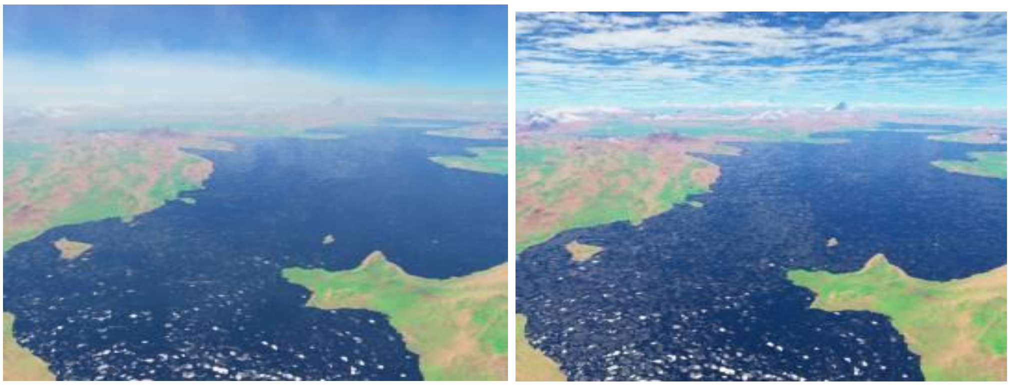


Figure 35. Examples of cloud's altitude set to 500 ft and 16000 ft height respectively.

3.3.1.6 **Cloud Density**

The parameter, cloud density is used to adjust the density levels of the clouds of any scenery that is created in Terragen. Using this, a normal good weather scenario can be changed into a thunderous, stormy looking scenario by assigning it values towards the higher limit. Its values range is from 0 to 0.1, where 0 creates a single layer of the cloud and 0.1 creates multiple layers. The range (0, 0.1) is mapped to (0, 255) for performing GA operations. Figure 36, gives best example when the cloud density is at low and high values.

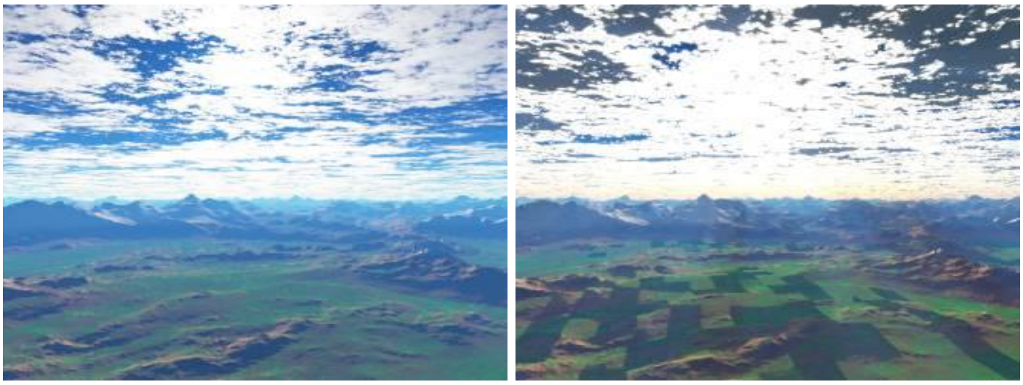


Figure 36. The cloud density level is shown in the same scene with low levels (Left) and high levels (Right).

3.3.1.7 **Cloud Depths**

This parameter defines the brightness and the eminence of the cloud seen in a landscape design created by Terragen. Its range is from 0 to 20000, where 0 indicates lowest brightness and light coloured clouds and the value 20000 indicates rigorous clouds with brighter colours. The range conversion is carried out similar to the cloud altitude parameter. Variation of different depth values on the cloud can be seen in figure 37.

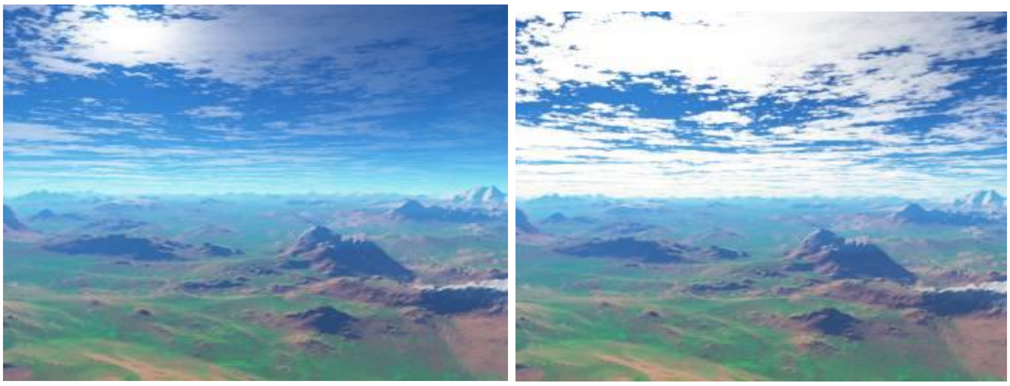


Figure 37. (Left) Cloud Depth at 20 and (Right) at 2000.

All the three parameters of cloud, altitude, density, and depth, require tuning simultaneously while creating any landscape design. Hence, the importance of each parameter and their effect on other parameters need to learn before using them. But, in this research, GA operates on these three parameters simultaneously tuning the three values according to the required output; i.e. demanded either by the user or by the aesthetic measures.

3.3.1.8 **Water level**

The parameter, water level, creates water into the scenery generated by Terragen. It is used to either increase or decrease the level of water over the surface. Its range is measured from -10000 to +10000 feet, where negative values indicate the depth levels of a sea bed and positive values indicates tide levels. When the water level is at maximum value, the terrains with height less than or equal 10000 feet will disappear, covered by plain water scenery. Figure 38 shows the visualisation of scenery with different water levels.

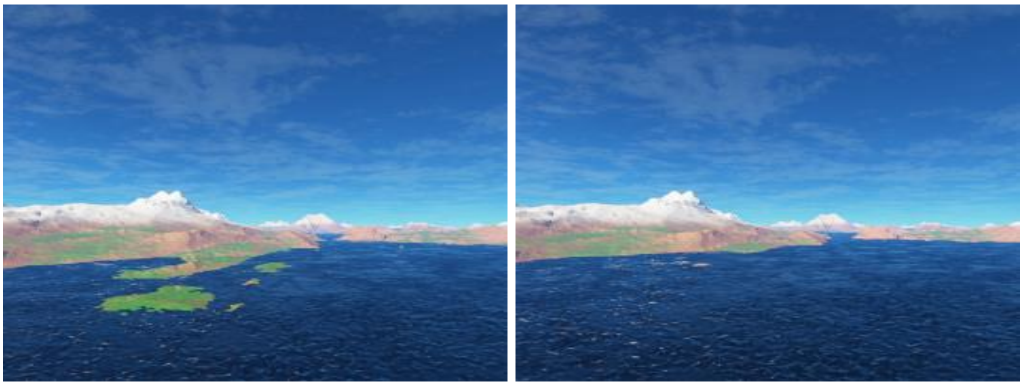


Figure 38. Water level test results show the difference when the value of 10 (Left) is increased to 100 (Right).

3.3.1.9 **Water Wave scale**

Water wave scale parameter creates waves over the water of scenery generated by Terragen. This parameter helps to visualise calm or rough conditions over the sea by adjusting the wave scale values provided by Terragen software. Its values range from 0 to 100, where value 0 indicates calm and smooth surface over the water and the value 100 causes huge height of water waves. The range (0, 100) is mapped to the range (0, 255) for performing GA operations. Figure 39 gives an example of how, a calm scenery can be converted into a horrifying scene, when the water wave scales are raised from 0 to 100.

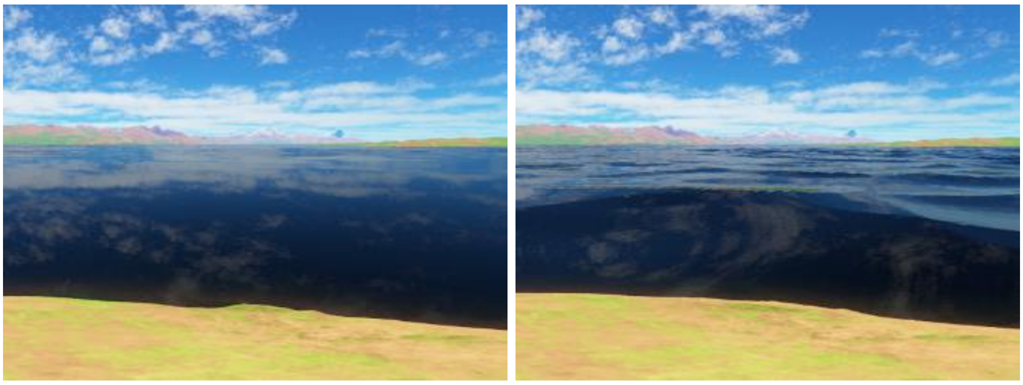


Figure 39. Water wave scale when the parameter wave scale is at (Left) 10 and (Right) 100.

3.3.1.10 **Water Roughness**

Along with the formation of the water waves, this parameter adds in roughness property. In Terragen, this property values range from 0 to 0.3, where 0 indicates a smooth surface of the water and the maximum value creating roughness. An example at minimum and maximum level of water is shown in figure 40. The range (0, 0.3) is mapped to the range (0, 255) for performing GA operations.

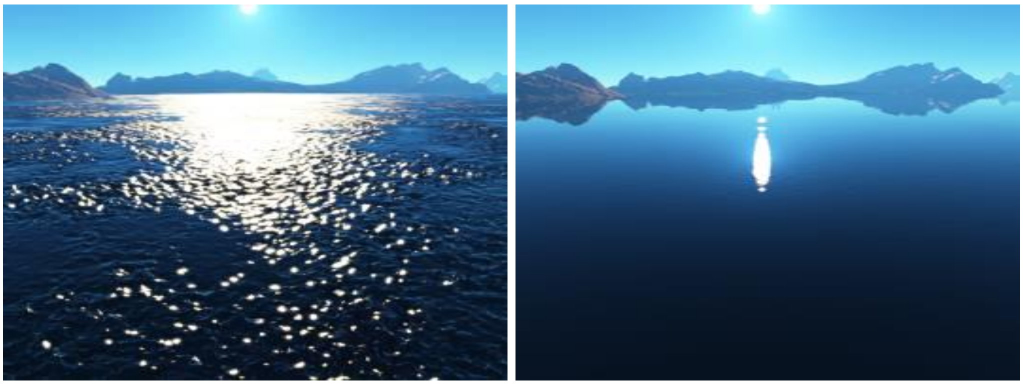


Figure 40. Variation in the same scenery when water roughness are set to 0.3 (Left) and 0.005 (Right).

3.3.1.11 **Texture Colours**

By using the Terragen GUI, colours of the scenery can be changed manually using the colour picker for objects such as grass, sand, rocks, water, cloud, sky, etc. For initial testing, in this research, only 3 textures colours were implemented and processed through GA operations. An example of changing colours of the same scenery is shown in figure 41. The colour format of Terragen is converted into RGB format by using Equation 4 and when needed reverted to the Terragen colour format by using Equation 5.

Equation for converting, Terragen colour format into Windows colour format

$$W_x = \left\{\left((T_x)^{\frac{1}{2.2}}\right) * 255\right\} \tag{4}$$

Equation for converting, Windows colour format into the Terragen colour format

$$T_x = \left(\frac{W_x}{255}\right)^{2.2} \tag{5}$$

Where, $W_x = Windows\ colour\ format\ of\ r, g\ and\ b\ values$

$T_x = Terragen\ colour\ format\ of\ r, g\ and\ b\ values$

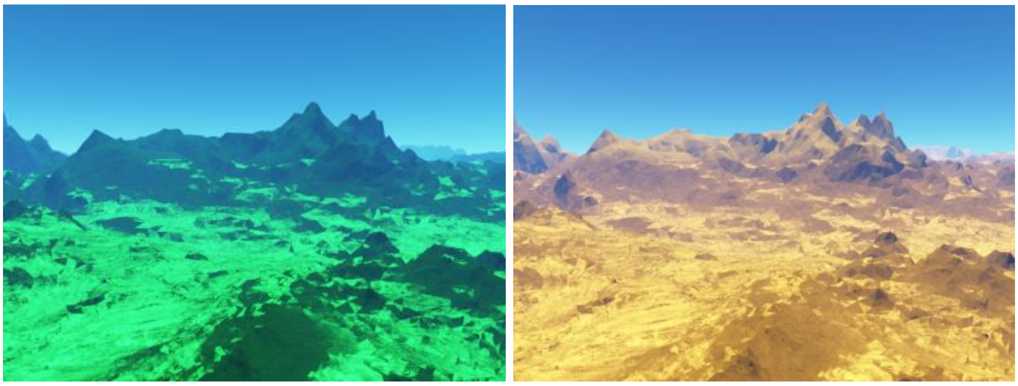
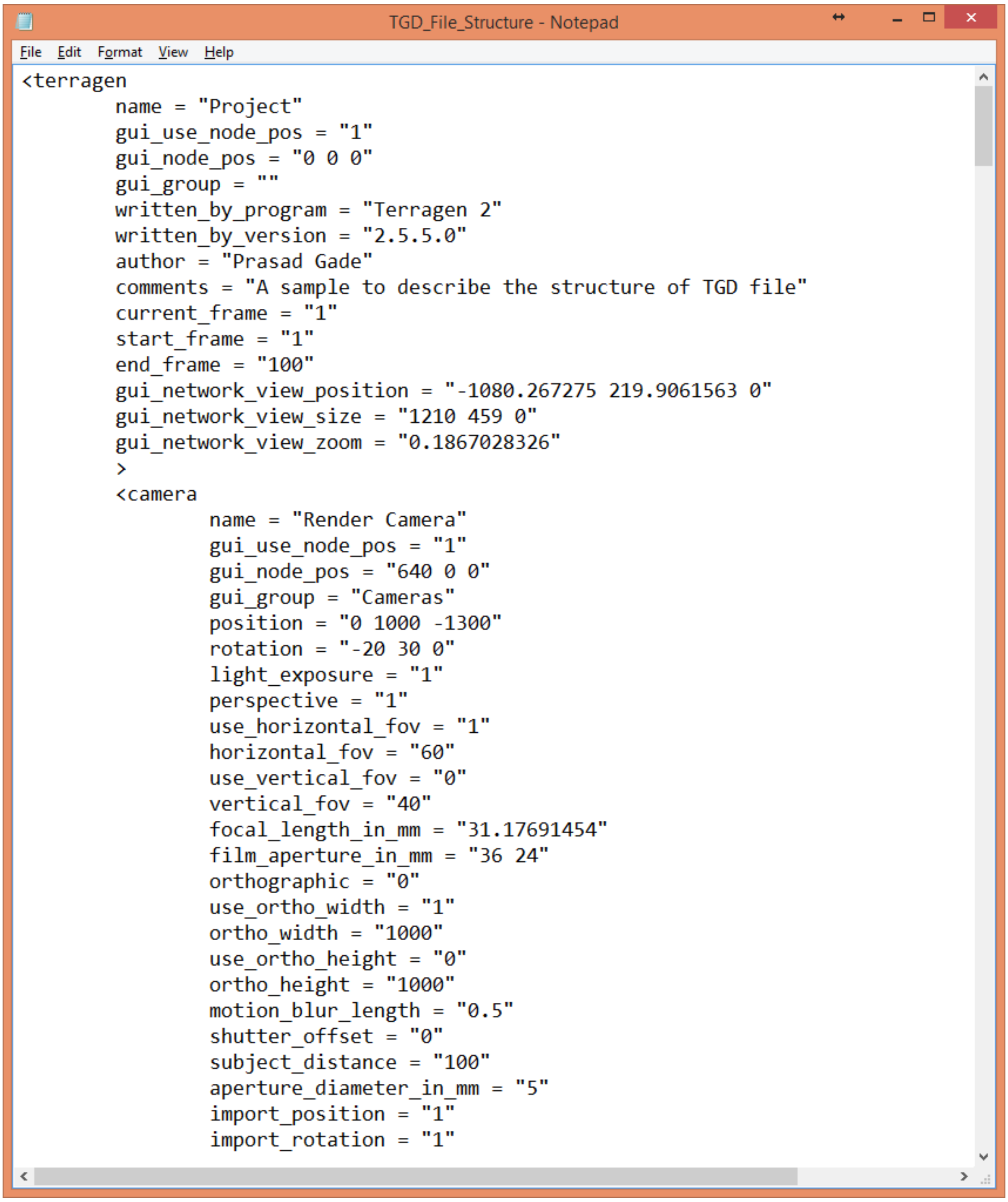


Figure 41. Same scenery changed from Alpine to Desert, when textures colours are changed.

3.3.1.12 **TGD file**

TGD file contains information of a landscape design generated by Terragen. The way information is stored is in XML format (as shown in figure 42), where each and every parameter that are involved in the creation of a landscape design is recorded with each parameters corresponding values. In this research, TGD files are created dynamically and fed into the Terragen software for converting them into images where necessary.



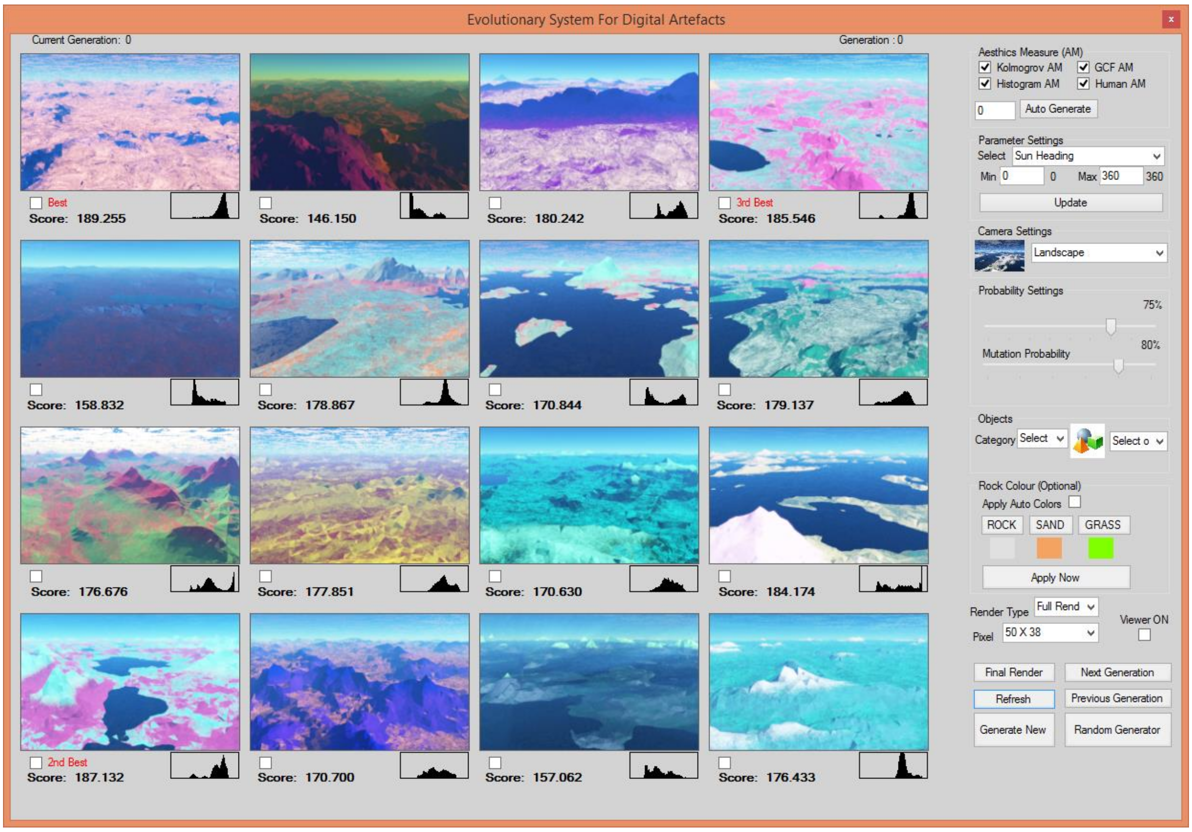
```
<terragen
        name = "Project"
        gui_use_node_pos = "1"
        gui_node_pos = "0 0 0"
        gui_group = ""
        written_by_program = "Terragen 2"
        written_by_version = "2.5.5.0"
        author = "Prasad Gade"
        comments = "A sample to describe the structure of TGD file"
        current_frame = "1"
        start_frame = "1"
        end_frame = "100"
        gui_network_view_position = "-1080.267275 219.9061563 0"
        gui_network_view_size = "1210 459 0"
        gui_network_view_zoom = "0.1867028326"
        >
        <camera
                name = "Render Camera"
                gui_use_node_pos = "1"
                gui_node_pos = "640 0 0"
                gui_group = "Cameras"
                position = "0 1000 -1300"
                rotation = "-20 30 0"
                light_exposure = "1"
                perspective = "1"
                use_horizontal_fov = "1"
                horizontal_fov = "60"
                use_vertical_fov = "0"
                vertical_fov = "40"
                focal_length_in_mm = "31.17691454"
                film_aperture_in_mm = "36 24"
                orthographic = "0"
                use_ortho_width = "1"
                ortho_width = "1000"
                use_ortho_height = "0"
                ortho_height = "1000"
                motion_blur_length = "0.5"
                shutter_offset = "0"
                subject_distance = "100"
                aperture_diameter_in_mm = "5"
                import_position = "1"
                import_rotation = "1"
```

Figure 42. An example of TGD file structure

3.3.2 Creation of landscape designs

3.3.2.1 Initialisation

At this phase, for both GA and IGA processes, a set of initial population is created by using a random initialisation technique. In total, sixteen TGD files are created with random parameter values, and sent to the Terragen render engine for converting their numerical representation into a graphical form before being displayed in a GUI, as shown in figure 43. If it is the case that the user is not satisfied with the initial generated population, they can generate another set of initial population by using the *Random Generator* tool. When the user is satisfied with the individuals that have appeared in the population group, the next stage of the process can be started.



Current Generation: 0
Generation : 0

□ Best Score: 189.255
□ Score: 146.150
□ Score: 180.242
□ 3rd Best Score: 185.546
□ Score: 158.832
□ Score: 178.867
□ Score: 170.844
□ Score: 179.137
□ Score: 176.676
□ Score: 177.851
□ Score: 170.630
□ Score: 184.174
□ 2nd Best Score: 187.132
□ Score: 170.700
□ Score: 157.062
□ Score: 176.433

☑ Kolmogrov AM ☑ GCF AM
☑ Histogram AM ☑ Human AM
0
Select Sun Heading
Min 0 0 Max 360 360
Landscape
75%
80%
Category Select Select o
Apply Auto Colors □
Render Type Full Rend
Pixel 50 X 38
Viewer ON □

Figure 43. Initial population generated by using randomized initialization process and displayed as Generation 0 in a user interface.

3.3.2.2 **Fitness Evaluation**

In this research, fitness evaluation of the landscape design is carried out by using two techniques, human evaluation and computational aesthetics measures.

For human fitness evaluation, IGA technique is used where the end-users are allowed to select and rank the top three images according to their aesthetics by using check boxes provided underneath each landscape design. Before ranking images, if required, the user can use optional tools such as; adjusting the probability levels for crossover and mutation operators, camera settings (angle, rotation, elevation and direction), generating image sizes, texture colours and rendering type (full or quick). When the user does not change these settings, the default settings are applied automatically to the generated landscape design.

For computational based fitness evaluation, aesthetic measures such as GCF, information theory and their combined aesthetic measure are used to evaluate and rank the best fitted landscape design automatically. The process of detecting the best fit landscape design by using aesthetic measures is clearly explained in Section 3.3.3. Using this functionality, the end-users can pre-set the number of generations to be run by the system and then can view the final results directly.

3.3.2.3 **Selection**

At this phase, a set of eight paired parents is selected by using a RRWS process, as shown in figure 3 for performing the reproduction process.

3.3.2.4 **Crossover**

During the crossover process, information is exchanged between two parent landscape designs to produce two new landscape designs called offspring. Before this operation is performed, each parameter value in both parents is converted into an 8-bit binary string for exchanging their attributes to one another using the two point crossover technique, as shown in the example in figure 5. Crossover operation is performed on each parameter between the two landscape designs. For example, water levels in Parent A and Parent B are re-combined to form new water levels for the offspring and so on until all the remaining parameters of both the landscapes are exchanged, which forms a complete set of parameters for a new two landscape design.

3.3.2.5 **Mutation**

In this phase, in order to bring alleles into the newly generated population group, the information is slightly altered by flipping over the bits at a random position point on a parent binary string as shown in figure 7. The mutation operation performed on the individual is based on the probability rate set by the creator.

3.3.2.6 **Next Generation**

After performing the genetic operations, a new set of sixteen TGD files is generated which are sent to the Terragen engine to convert the newly born offspring into their visual representation, i.e. as landscape designs. The newly generated population is presented back into the system as Generation 1. The whole process, from fitness evaluation phase to the next generation phase is repeated until the termination point is reached, i.e. either when the end-user is satisfied with the evolved results or when the target number of generations is met while using aesthetic measure evaluation.

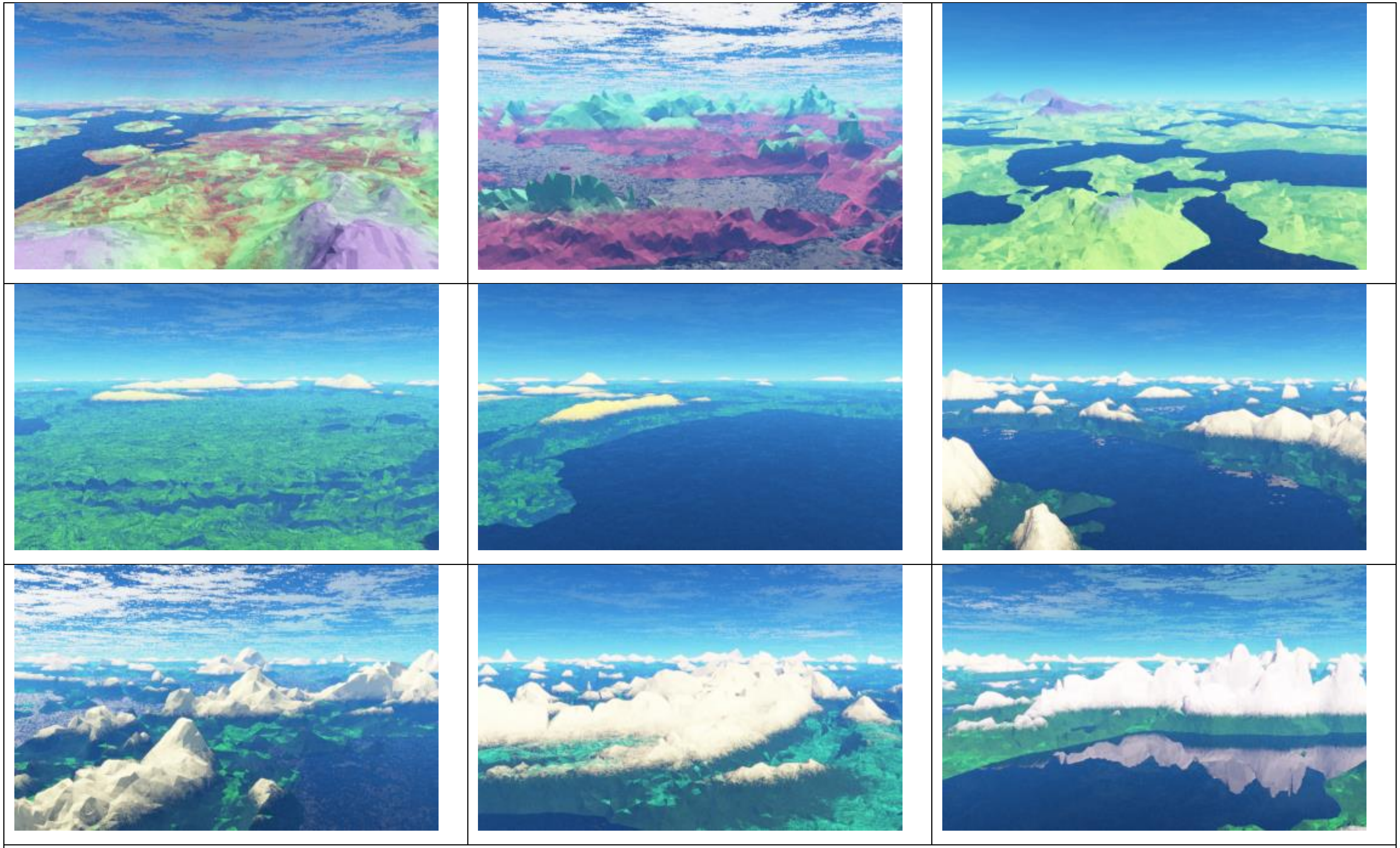


Table 10. Evolution of Alpine scenery; successive individuals from initial generation to generation 25, are listed in this table.

3.3.3 Computational aesthetic fitness measures

To replace user involvement during the fitness evaluation phase, aesthetic measures are implemented to determine the aesthetically pleasing landscape designs by using both information theory and GCF measure. Depending on the results obtained, the top three fitness valued landscape designs are selected automatically in each generation.

3.3.3.1 **GCF**

Matkovic et al. [16] introduced a new approach to calculate contrast levels of an image. Before the GCF is calculated, the original image is converted into a greyscale image. There are two steps involved in this process, one is to calculate local contrast factor and then add it together with a weighting factor.

Step 1: Calculate local contrast factor

The local contrast is an average value of neighbouring pixels where each pixel is gamma corrected before achieving perceptual luminance *L* by using Equation 6.

$$L = 100 * \sqrt{l} \qquad (6)$$

Where *l* is the linear luminance of each pixel with applied gamma correction, γ = *2.2,* as shown in Equation 7.

$$l = \left(\frac{k}{255}\right)^{\gamma} \qquad (7)$$

For each four surrounding perceptual luminance, $lc_{i,}$, a local contrast factor C_i is created by using Equation 8.

$$lc_i = \frac{|L_i - L_{i-1}| + |L_i - L_{i+1}| + |L_i - L_{i-w}| + |L_i - L_{i+w}|}{4} \qquad (8)$$

C_i in Equation 9 is an average local contrast factor which is used to compute the average of all the local contrast factors, $lc_{i,,}$ that are produced at various resolutions. In this research, six local contrast factors are performed.

$$C_i = \frac{1}{w * h} \sum_{i=0}^{N} lc_i \tag{9}$$

At this stage the original image has been reduced to half of its size in height and width by transforming each pixel into a new ‘super pixel’. A super pixel is an average of its surrounding pixel values. Figure 44 shows the size of the original image divided into 4 different resolutions where the averaging of local contrast factors is performed.

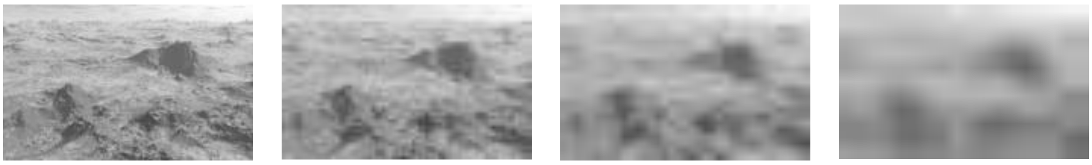


Figure 44. Super Pixels stage at various resolutions.

Step 2: Add weighting factor

In the final step, the authors evaluate the GCF value with the summation of the entire average local contrast factor, generated by weighting factors as shown in Equation 10.

$$GCF = \sum_{i=1}^{N} w_i * C_i \tag{10}$$

Where,

$$\mathrm{w_i} = \left(-0.406385 * \frac{\mathrm{i}}{9} + 0.334573\right) * \frac{\mathrm{i}}{9} + 0.0877526 \tag{11}$$

The two landscape designs, with their fitness values, are shown in figure 45, after GCF aesthetic test is performed.

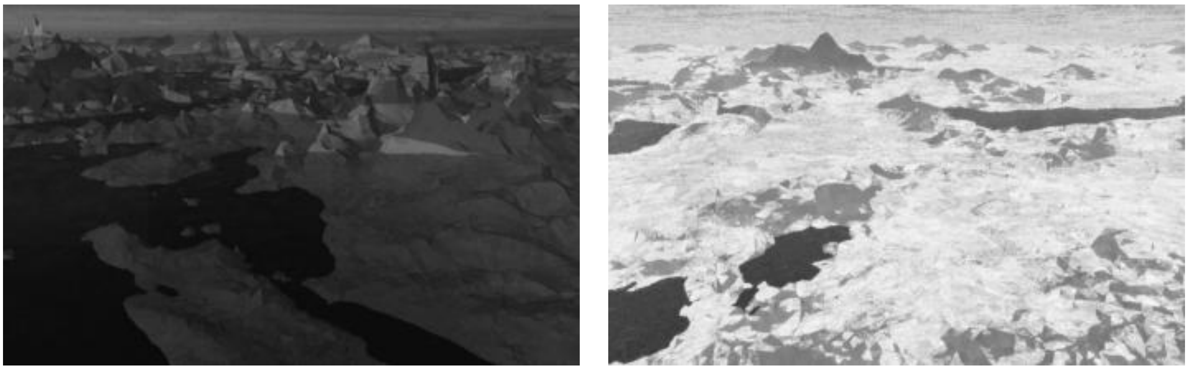


Figure 45. GCF value of the left side image is 2.2695393 and right side image is 11.2654189.

3.3.3.2 **Information Theory**

As noted in *Informational Aesthetic Measure* [88] the quantitative aesthetic measures have been studied since at least 1928 when Birkhoff [8] formulated an aesthetic evaluation of an entity as the ratio between order and complexity. While such notions of evaluating the aesthetic beauty of objects via a computational method may seem fanciful, researchers since Birkhoff have limited their efforts to restricted groups of observers and only make comparisons between similar objects.

Informational techniques are still largely based on the concept suggested by Birkhoff: that aesthetic appreciation stems from the ratio of complexity C to order O within an object:

$$M = \frac{O}{C} \tag{12}$$

In information theory, entropy is a measure of the order or uncertainty associated with a random variable and usually is gauged by Shannon entropy. This quantifies the expected value of the information contained in a message, usually in units such as bits. Shannon's entropy represents an absolute limit on the best possible lossless compression of any communication, under certain constraints. This treats messages to be encoded as a sequence of independent and identically-distributed random variables. In algorithmic information theory the Kolmogorov complexity of an object, such as a piece of text, is a measure of the computational resources needed to specify the object. These concepts are exploited in Birkhoff, where a measure of the order in an image is estimated by the difference between the image size (obtained using a constant length code for each colour) and its Kolmogorov complexity. This corresponds to the space saving defined as the size reduction relative to the uncompressed size, which gives us this aesthetic fitness measure:

$$M = \frac{NH_{max} - K}{NH_{max}} \tag{13}$$

Where, the maximum entropy log $|N_b^{rgb}|$ denoted H_{rgb} of an RGB colour representation of N pixels achieved by N random variables X_{rgb} is equal to 24. As in (*Using Aesthetic Measure to evolve Art* [84]) this research also estimates K by the use of the JPEG compression algorithm. The JPEG compressor exploits both the selected palette’s degree of order and the colour position in the canvas. Rigau identified the JPEG compressor as a good estimate of algorithmic complexity because of its ability to discover patterns, in spite of losing information that’s imperceptible by the human eye. To avoid losing key visual information, we use a JPEG compressor with the maximum quality option.

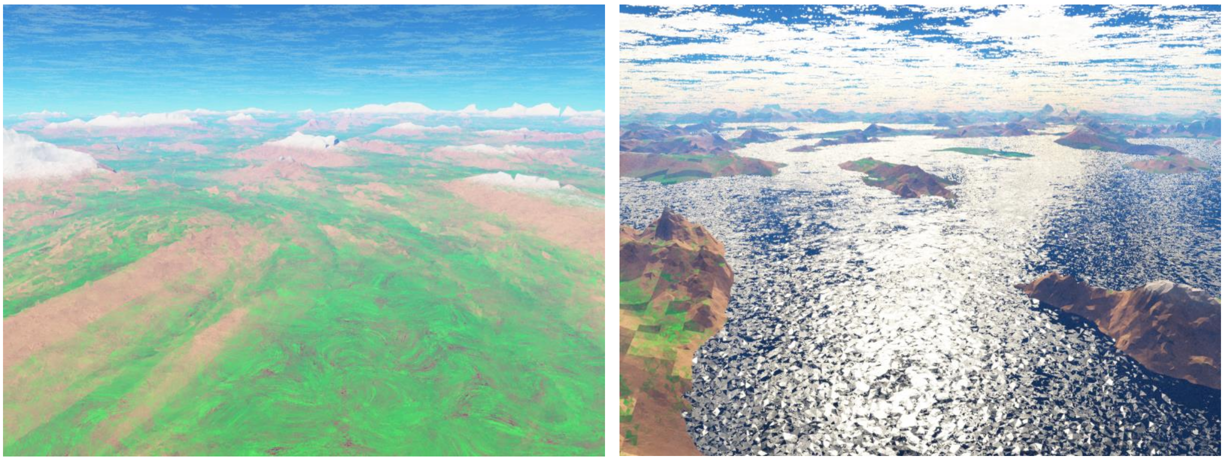


Figure 46. Information theory aesthetic value of the left side image is 59.380 and right side image is 89.788.

3.3.3.3 **Combined Aesthetic Measure**

A final aesthetic measure for evaluating landscape designs is created by normalizing both GCF and information theory. The final score for each landscape design is calculated by using Equation 16. Based on the final results, after the fitness evaluation test is performed, the top three scored landscape designs are automatically selected to perform the remaining phases involved in GA process.

$$GCF\_Score = \frac{(GCF_V - S_{min}) * (S_{Max} - S_{min})}{(GCF_{Max} - GCF_{min})} \tag{14}$$

$$K\_Score = \frac{(K_V - S_{min}) * (S_{Max} - S_{min})}{(K_{Max} - K_{min})} \tag{15}$$

$$\Rightarrow \boldsymbol{TotalScore} = \frac{GCF_{Score} + K\_Score}{2 * (S_{Max})} \tag{16}$$

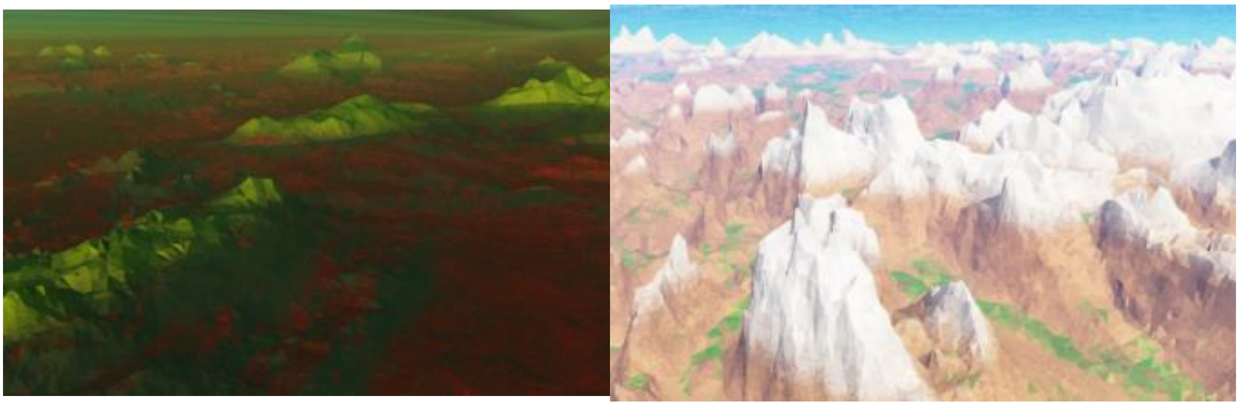


Figure 47. Combined GCF and Information theory measured values between the left side image is 2.316 and right side image is 11.680.

3.4 Evolving Website colour schemes

3.4.1 Genome Representation

For initial testing, in this research, only seven coloured components were used in the website template for identifying their proper combinations through evolutionary search. The remaining coloured components are kept as constant values while creating a genome string as shown in figure 49. The seven colour components that are implemented in this research are shown below:

1. Banner – this is treated as the main colour of a website
2. Banner Text – this is the main heading colour of a website
3. Banner background – this is the background colour for the banner text
4. Buttons – this is for all the button colours used in a website

5. Button Text – this is for the text colour layered on the buttons
6. Main Section – this is the main colour used text area
7. Bold Letters – this colour is for headings, bold texts etc.
8. Normal Letters – this colour is used for normal font letters

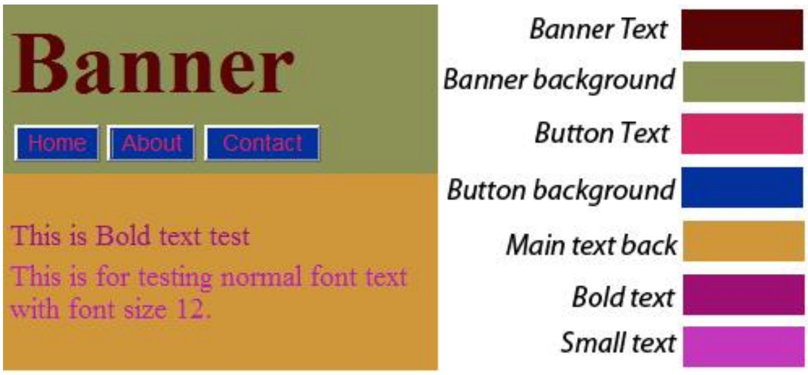


Figure 48. Template describes website colours

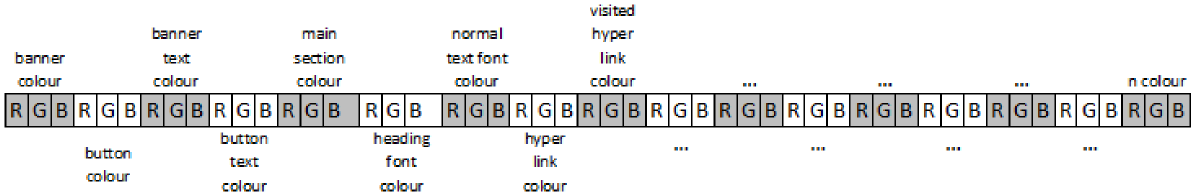


Figure 49. A complete set of genome string for a website colour design

During the evolutionary process of identifying the colour scheme for a website design, certain rules link the colour components which mean that the combinations are tested against each other. These links are as described in Table 11.

No.	Set of Rules
1	Banner text colour against its background colour, i.e. banner colour
2	Button colour against its background colour, i.e. again banner Colour
3	Button text colour against its button colour
5	Bold text colour against its main section background colour
6	Normal text colour against its main section background colour

Table 11. Set of rules to rank website template

3.4.1.1 **HTML file**

Information of a website design is stored in the HTML (Hyper Text Markup Language) format. Internet browsers, such as Internet Explorer, Firefox, Chrome, Safari, etc. read html files and generate each files visual representation. The information stored by using elements is described in Algorithm 5. The colours used in a website design can be represented using html tags or stored in a separate file called Cascading Style Sheet (CSS), as described in Algorithm 6. CSS helps designers to maintain a uniform style throughout the whole website. For example, heading colour and size, background and foreground colour of the text, etc. can be changed in one file i.e. CSS, and the effect can be seen on all the multiple pages that are linked to the main website.

Algorithm 5: A simple html file with internal style sheet

```
<!DOCTYPE html>

<html>

<body>

<h2>This is bold or heading text</h2>
<p>This is a normal text font.</p>

<button type="button">Home</button>
<button type="button">About us</button>
<button type="button">Contacts</button>

<table>

<tr><td>row 1, column 1</td></tr>
<tr><td>row 2, column 2</td></tr>
<tr><td>row 3, column 3</td></tr>

</table>

</body>

</html>
```

Algorithm 6: A simple CSS file to change body background, button background heading and text colors

```
body
{
     background-colour: #d0e4fe;
}
h2
{
     colour: orange; or color: rgb(255,255,0);
     text-align: centre;
}
Button
{
      background-color:#ffffff;
      color:#000000;
      font-family:arial;
      font-size:15px;
      font-weight:bold;
      font-style:normal;
      height:50px;
      width:100px;
}
p
{
     font-family: "Times New Roman";
     font-size: 20px;
     text-indent: 50px;
     text-align: justify;
     color:rgb(0,0,0);
}
```

3.4.2 Creation of website colour schemes

Website colours are updated dynamically by creating a new CSS file for each individual website. IGA technique is implemented, allowing the end-user to guide the evolution of colour schemes, which is the same procedure followed for evolving landscape designs except in this case, html files are used instead of TGD files. GA technique is implemented by using aesthetic measures to perform fitness evaluation test which is carried out in three different stages as follows:

Stage 1:

At stage 1, based on the colour input given by the user i.e. banner colour, the best fit colour combinations of the components; banner background, main text area and button background colours, are evolved by using GA technique. The flow chart diagram for stage 1 process is shown in figure 50.

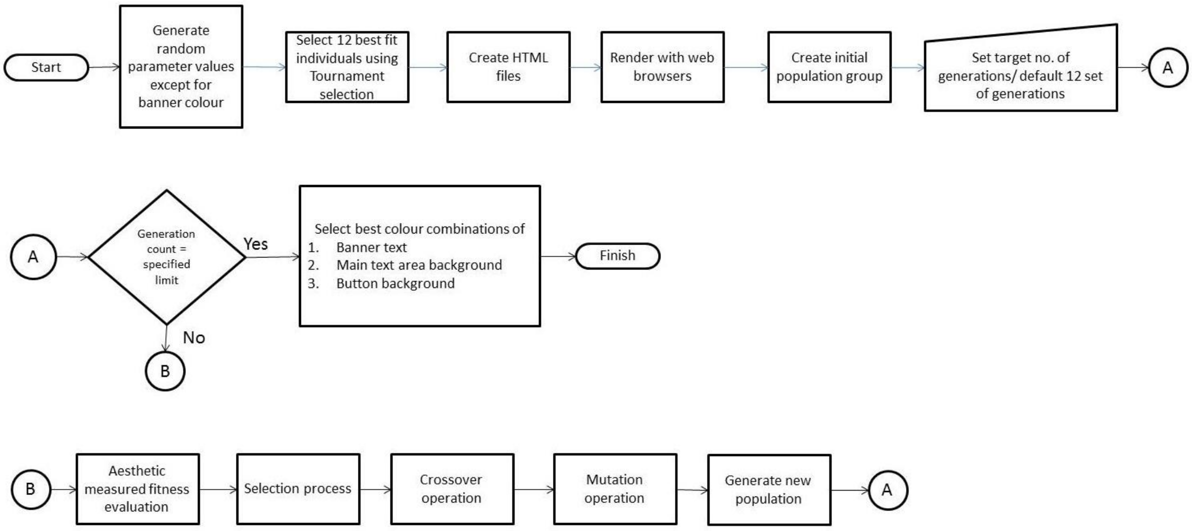

Start
Generate random parameter values except for banner colour
Select 12 best fit individuals using Tournament selection
Create HTML files
Render with web browsers
Create initial population group
Set target no. of generations/ default 12 set of generations
A
A
Generation count = specified limit
Yes
Select best colour combinations of
1. Banner text
2. Main text area background
3. Button background
Finish
No
B
B
Aesthetic measured fitness evaluation
Selection process
Crossover operation
Mutation operation
Generate new population
A

Figure 50. Flow chart diagram for stage 1 process in the evolution of colour combination of banner text, main text area background and button background colours.

Stage 2:

Based on the result for the main section background colour obtained from stage 1, the best fitted colour combinations of normal font text and bold/heading text colours are evolved by using GA technique. The flow chart diagram for stage 2 process is shown in figure 51.

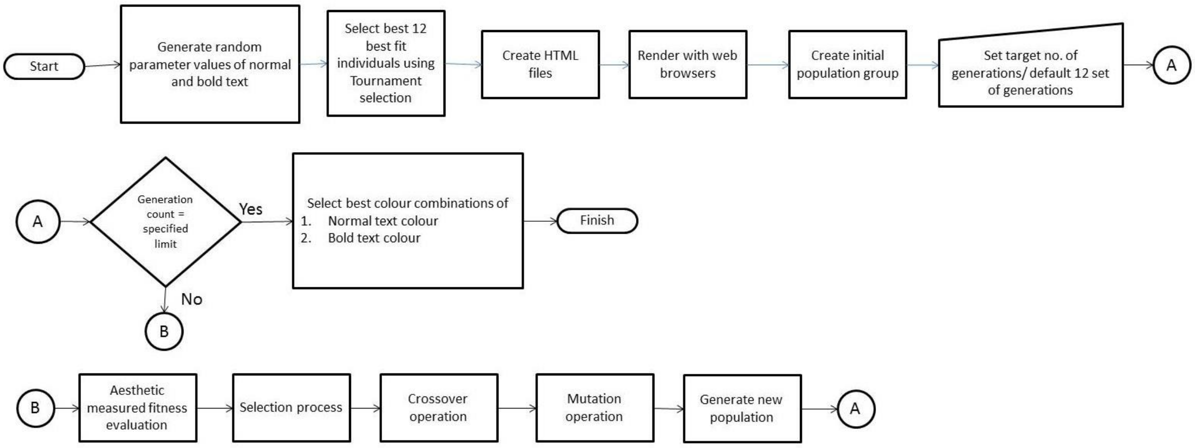

Start
Generate random parameter values of normal and bold text
Select best 12 best fit individuals using Tournament selection
Create HTML files
Render with web browsers
Create initial population group
Set target no. of generations/ default 12 set of generations
A
A
Generation count = specified limit
Yes
Select best colour combinations of
1. Normal text colour
2. Bold text colour
Finish
No
B
B
Aesthetic measured fitness evaluation
Selection process
Crossover operation
Mutation operation
Generate new population
A

Figure 51. Flow chart diagram for stage 1 process in the evolution of colour scheme generations

Stage 3:

Again based on the results obtained from stage 1, but for button background colour, the best fit colour combination of button text colour is evolved using the same GA technique. The flow chart diagram for stage 3 process is shown in figure 52.

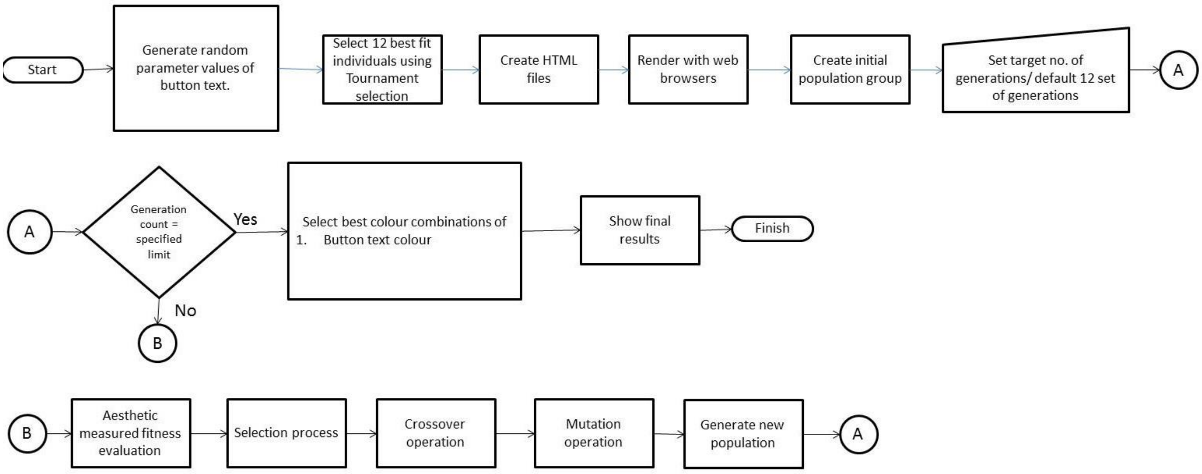

Start
Generate random parameter values of button text.
Select 12 best fit individuals using Tournament selection
Create HTML files
Render with web browsers
Create initial population group
Set target no. of generations/ default 12 set of generations
A
A
Generation count = specified limit
Yes
Select best colour combinations of
1. Button text colour
Show final results
Finish
No
B
B
Aesthetic measured fitness evaluation
Selection process
Crossover operation
Mutation operation
Generate new population
A

Figure 52. Flow chart diagram for stage 1 process in the evolution of colour scheme generations

From stage 1 to stage 3, EC framework automatically guides itself by locking and saving the colours that are obtained in each stage, giving the final results (a total colour scheme) to the end-user.

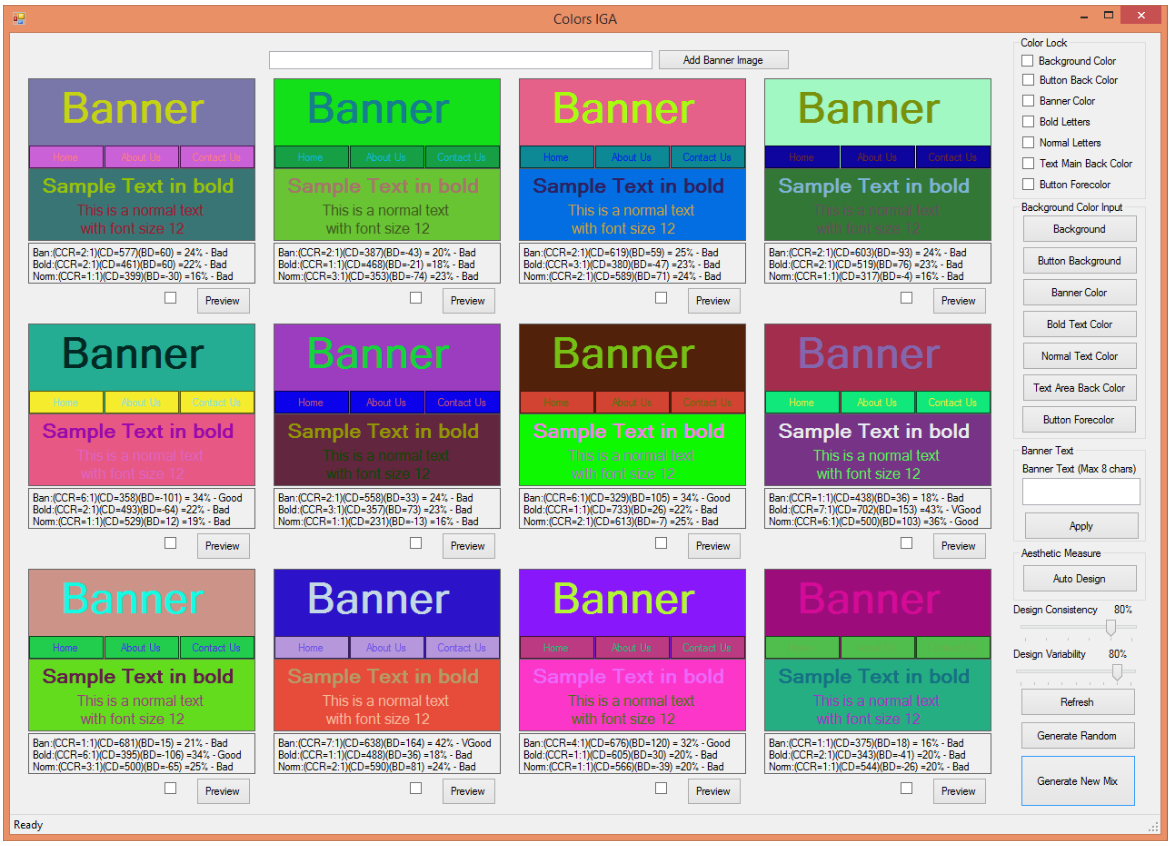
The genetic operations initialization, fitness evaluation, selection, crossover, mutation and new generations stay common in all the three stages of the operation.

3.4.2.1 **Initialization**

During the initialization phase, a set of twelve html files is created to visualize the basic designs of a simple website, shown in figure 48. The selection of individuals (website templates) while creating the initial population is carried out in two different ways, (1) randomly generated individuals while using IGA technique and (2) tournament selection while using GA technique.

For human fitness evaluation based technique (IGA), a set of randomly generated colour schemes are applied to each website template to form an initial population group as shown in figure 53. If the user is not satisfied with the initially populated colour schemes, they can re-generate initial population group any number of times by using *RandomGen* tool.

For computational aesthetic fitness measure based technique (GA), the initialization process is carried out by selecting the best fitted individuals for the initial population by performing the tournament selection. The fitness function used for calculating the individual's fitness score is the combined aesthetic measure of CCR, CD and BD (See Section 3.4.3.4).



```
Ban:(CCR=2:1)(CD=577)(BD=60) = 24% - Bad
Bold:(CCR=2:1)(CD=461)(BD=60) =22% - Bad
Norm:(CCR=1:1)(CD=399)(BD=-30) =16% - Bad

Ban:(CCR=2:1)(CD=387)(BD=-43) = 20% - Bad
Bold:(CCR=1:1)(CD=468)(BD=-21) =18% - Bad
Norm:(CCR=3:1)(CD=353)(BD=-74) =23% - Bad

Ban:(CCR=2:1)(CD=619)(BD=59) = 25% - Bad
Bold:(CCR=3:1)(CD=380)(BD=-47) =23% - Bad
Norm:(CCR=2:1)(CD=589)(BD=71) =24% - Bad

Ban:(CCR=2:1)(CD=603)(BD=-93) = 24% - Bad
Bold:(CCR=2:1)(CD=519)(BD=76) =23% - Bad
Norm:(CCR=1:1)(CD=317)(BD=-4) =16% - Bad

Ban:(CCR=6:1)(CD=358)(BD=-101) = 34% - Good
Bold:(CCR=2:1)(CD=493)(BD=-64) =22% - Bad
Norm:(CCR=1:1)(CD=529)(BD=12) =19% - Bad

Ban:(CCR=2:1)(CD=558)(BD=33) = 24% - Bad
Bold:(CCR=3:1)(CD=357)(BD=73) =23% - Bad
Norm:(CCR=1:1)(CD=231)(BD=-13) =16% - Bad

Ban:(CCR=6:1)(CD=329)(BD=105) = 34% - Good
Bold:(CCR=1:1)(CD=733)(BD=26) =22% - Bad
Norm:(CCR=2:1)(CD=613)(BD=-7) =25% - Bad

Ban:(CCR=1:1)(CD=438)(BD=36) = 18% - Bad
Bold:(CCR=7:1)(CD=702)(BD=153) =43% - VGood
Norm:(CCR=6:1)(CD=500)(BD=103) =36% - Good

Ban:(CCR=1:1)(CD=681)(BD=15) = 21% - Bad
Bold:(CCR=6:1)(CD=395)(BD=-106) =34% - Good
Norm:(CCR=3:1)(CD=500)(BD=-65) =25% - Bad

Ban:(CCR=7:1)(CD=638)(BD=164) = 42% - VGood
Bold:(CCR=1:1)(CD=488)(BD=36) =18% - Bad
Norm:(CCR=2:1)(CD=590)(BD=81) =24% - Bad

Ban:(CCR=4:1)(CD=676)(BD=120) = 32% - Good
Bold:(CCR=1:1)(CD=605)(BD=30) =20% - Bad
Norm:(CCR=1:1)(CD=566)(BD=-39) =20% - Bad

Ban:(CCR=1:1)(CD=375)(BD=18) = 16% - Bad
Bold:(CCR=2:1)(CD=343)(BD=-41) =20% - Bad
Norm:(CCR=1:1)(CD=544)(BD=-26) =20% - Bad
```

Figure 53. GUI shows randomly generated colour scheme for each individual in set of initial population.

3.4.2.1 **Fitness Evaluation**

In this phase, fitness evaluation test is performed on each individual from the present population. While using GA technique, computational aesthetic measures perform fitness test on each individual and selects the top three best fitted individuals automatically, explained in Section 3.4.3. For IGA based technique, the user has to select the top three colour scheme website templates manually before the next phase.

3.4.2.2 **Selection**

In this phase, a set of six paired individuals is selected as parents by using RRWS technique. The probability of being selected among twelve individuals for reproduction process is totally dependent on the ranking system performed during the fitness evaluation phase as shown in figure 3.

3.4.2.3 **Crossover**

During crossover operation, a particular component colour in Parent A is only crossed over with the associated component colour in Parent B. For example, banner text colour in Parent A is applied to banner text colour in Parent B and button colours in Parent A is applied to button colours in Parent B and so on. RGB values of each channel are converted into 8-bit binary format separately, i.e. r, g and b. At a random crossover point bits are exchanged between each parent component colours giving birth to new component colours as shown in figure 54.

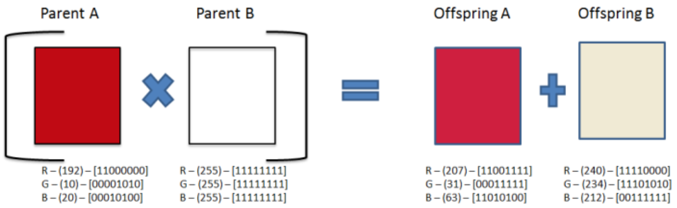


Figure 54. Performing Crossover operation over two colours

3.4.2.4 **Mutation**

In the mutation process, bits in the parent binary string are flipped over at random position points to bring new features onto the newly born offspring. An example is shown in figure 55, the parent colours red and white have given rise to the offspring colours green and pink respectively.

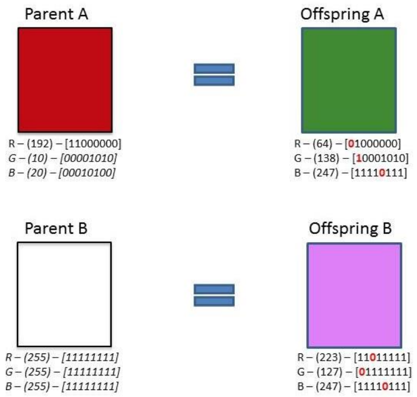


Figure 55. Performing Mutation operation over two colours

3.4.2.5 **Next Generation**

In this phase, the set of newly generated offspring individuals is sent back to the fitness evaluation phase as generation 1, to continue the evaluation process. The end-user is then allowed to rank three best fitted website templates, colour schemes, to achieve generation 2 and then generation 3 and so on. The whole process is carried out till the user is satisfied with the evolved results according to their aesthetics.

In the case where computational aesthetic measures are driving the evolutionary process for generating website colour schemes, the whole process is repeated from a fitness evaluation phase to generating new population phase automatically, until the user specified number of generations is met.

3.4.3 Computational aesthetic fitness measures

Three types of Aesthetic measures were used in this research to identify proper colour combinations between any given two colours. This is done with the aim to create colour schemes for readability of text that would suit most users. The W3C provided open source algorithms that can perform a readability check for colour combinations [19]. The three main aesthetic measures they provided are CCR, CD and BD. By using these three aesthetic measures, this research created a fourth aesthetic measure called CAMCC (Combined Aesthetic Measure for Colour Combination) by combining them into one after normalizing their aesthetic measures into the same range. Formula and their properties of all the aesthetic measures used in this research are described below.

3.4.3.1 **Colour Contrast Ratio**

CCR fitness measure checks for relative luminance between the background and foreground colours. The luminance of each colour is calculated by using the Equation 17.

$$L = (0.2126 * R) + (0.7152 * G) + (0.0722 * B) \tag{17}$$

Where R, G and B values are calculated as follows:

- $if\left(\left(\frac{rValue}{255}\right)^{2.4} \leq 0.03928\right) then\ \boldsymbol{R} = \frac{rValue}{12.92} else\ \boldsymbol{R} = \left(\frac{rValue+0.055}{1.055}\right)^{2.4}$

- $if\left(\left(\frac{gValue}{255}\right)^{2.4} \leq 0.03928\right) then\ \boldsymbol{G} = \frac{gValue}{12.92} else\ \boldsymbol{G} = \left(\frac{gValue+0.055}{1.055}\right)^{2.4}$

- $if\left(\left(\frac{bValue}{255}\right)^{2.4} \leq 0.03928\right) then\ \boldsymbol{B} = \frac{bValue}{12.92} else\ \boldsymbol{B} = \left(\frac{bValue+0.055}{1.055}\right)^{2.4}$

The luminance ratio between the two colours is calculated by using Equation 18. Where, *L1* is the relative luminance of the foreground colour, and *L2* is the relative luminance of the background colour.

$$Luminance\ Ratio = \frac{(L1 + 0.05)}{(L2 + 0.05)} \tag{18}$$

Using the results obtained from the luminance ratio values, the relationship between the two colours is identified with the help of W3C Guidelines, G17 and G18 [103]. According to their guidelines, depending on the font size, only the colour contrast ratio levels that are more than 4.5:1 between any two colours are considered to be a good pair, below that ratio level problem could arise with the readability of text for most users. The maximum ratio level that it can reach is 21:1, i.e. between black and white colours. W3C recommended two different ratio levels depending on the size of the text as follows:

- Guidelines G18 – recommends that a contrast ratio should be at least 4.5:1 between text colour and its background colour, when the font size is less than 18 point if not bold or 14 point if bold.

- Guidelines G17 – recommends that a contrast ratio should be at least 7:1 exists between text colour and its background colour, when the font size is more than 18 points.

In this research, an additional algorithm is developed to check the size of the font used in a website for applying recommended Guidelines by W3C. If the size of the font is more than 18 point, then the luminance ratio suggested by G17 is applied into the aesthetic measure, and if the font size is less than 14 point then, G18 limitations on the luminance ratio levels are applied automatically.

3.4.3.2 **Colour Difference**

Colour difference is an important property to consider while mixing colours. It helps to identify the differences between the two colours. With the help of W3C algorithms, CD can be calculated by using Equation 22. For example, difference between *colour-A* (*R1, G1, B1*) and *colour-B* (*R2*, *G2*, *B2*) is calculated by the following sequence:

$$RedD = Max(R1, R2) - Min(R1, R2) \tag{19}$$

$$GreenD = Max(G1, G2) - Min(G1, G2) \tag{20}$$

$$BlueD = Max(B1, B2) - Min(B1, B2) \tag{21}$$

$$Colour\ Difference(CD) = RedD + GreenD + BlueD \tag{22}$$

The limitations set by W3C for CD value between any two colours should be greater than or equal to 500 [128]. The values less than 500 could lead to a possibility of dissolving in themselves, making it difficult to differentiate between those two colours and would have an effect on the user to read the text. Between black and white colours the CD value is 765 and between pink and red colours are 219. For example, it is easier to read black and white colour combinations, whereas for pink and red, it is difficult to identify the text, either for red on pink or pink on red colour combinations.

3.4.3.3 **Brightness Difference**

BD is tested to determine the variance of brightness levels between any two colours. If the brightness property in the two colours is set to too high or too low could result in difficulty to distinguish or read the text. To achieve proper brightness level balance between the colours, W3C proposed an algorithm to check the difference value by using Equation 25, where *C1* and *C2* are set to be background and foreground colours respectively.

$$C1 = \frac{\big((R1 * 299)\big) + (G1 * 587) + (B1 * 114)}{1000} \tag{23}$$

$$C2 = \frac{\big((R2 * 299)\big) + (G2 * 587) + (B2 * 114)}{1000} \tag{24}$$

$$\Rightarrow BD = \mathrm{Max}(\mathrm{C1}, \mathrm{C2}) - Min(C1, C2) \tag{25}$$

W3C set limitations for identifying the proper brightness balance difference between the two colours to avoid poor visibility. The range for the BD value is set to be greater than or equal 125 [128]. If the value drops down lower than 125 it could affect colours by showing as dimming or an increase in brightness levels between any two colours, which has an effect on readability.

3.4.3.4 **Combined Aesthetic Measure**

In this research, CCR, CD and BD values are combined together to create a fourth aesthetic measure called CAMCC. By using this aesthetic measure, the final score of the colour combinations is calculated to rank each individual based on their fitness score. To calculate the CAMCC aesthetic value, at first CCR, CD and BD aesthetic values are brought into the same level by normalizing their ranges and then added together to make a final score. The minimum and maximum values during normalization are taken from W3C guideline i.e. the value obtained between black and white colours is taken as the maximum value and the value obtained between the same colours combinations i.e. red on red, white on white, etc. is considered as least value.

Normalized CCR (nCCR) is calculated by using Equation 26. Where, value 21 in this equation refers to the highest value that CCR can reach, i.e. between black and white colour combinations. Based on that, the remaining CCR values are calculated accordingly.

$$nCCR = \frac{\mathrm{CCRvalue} * \ 100}{21} \tag{26}$$

Normalized CD (nCD) is calculated by using Equation 27. The value 765 in this equation refers to the maximum value that colour difference can reach, i.e. the brightness variation between the black and white colours. Based on this logic, the remaining BD values of other colour combinations are calculated accordingly.

$$nCD = \frac{\mathrm{CDvalue} * \ 100}{765} \tag{27}$$

Normalized BD (nBD) is calculated by using Equation 28. According to W3C, the BD value should be greater than or equal to 125. But, the maximum value of BD between black and white colours is 255. Hence, the value 255 is used in Equation 28 to calculate the rest of the colour combinations accordingly.

$$nBD = \frac{\mathrm{BDvalue} * \ 100}{255} \tag{28}$$

When all the nCCR, nCD and nBD values are obtained, they are fused into the CAMCC equation to get the final score by using Equation 29. Here as seen, nCCR, nCD and nBD contribute an equal share in the final score.

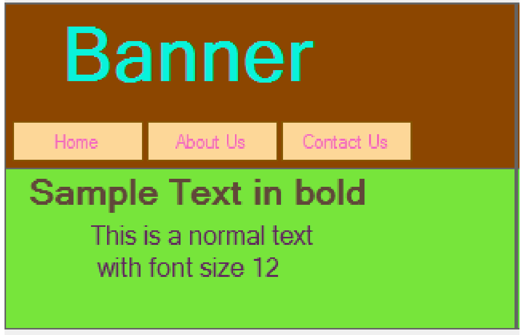
$$CAMCC = \frac{(\mathrm{nCCR} + \mathrm{nCD} + \mathrm{nBD})}{3.33} \tag{29}$$

To give an example of how aesthetic measure scores colour combinations, four samples of colour combinations are taken and based on their aesthetic measures ranking is done as shown in Table 12.

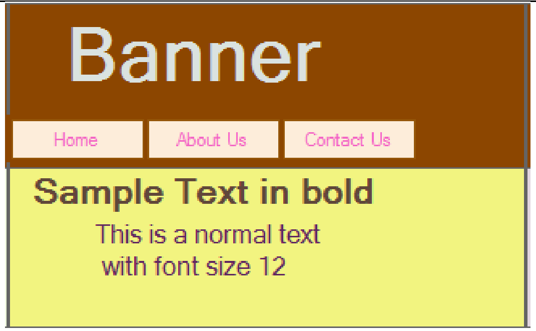
Samples	Colour combinations	CCR nCCR	CD nCD	BD nBD	CAMCC	Rank
1	Smaller Text **Larger**	5.7:1 27.14%	388 50.72%	142.6 55.92%	40.17	3
2	Smaller Text **Larger**	2.5:1 11.90%	315 41.18%	96.7 37.92%	27.33	4
3	Smaller	13:1	550	196.6	63.33	1

	Text **Larger**	61.90%	71.90%	77.10%		
4	Smaller Text **Larger**	7.2:1 34.29%	362 47.32%	150 58.82%	42.17	2

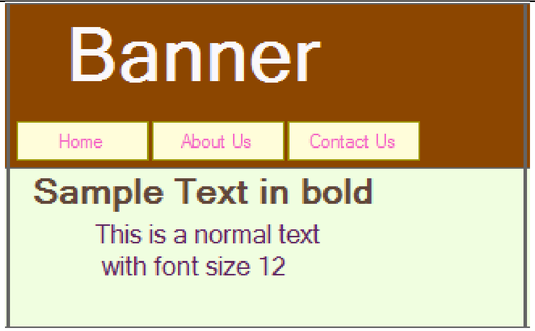
Table 12. Ranking colour combinations by using the CAMCC aesthetic measure.



(a)

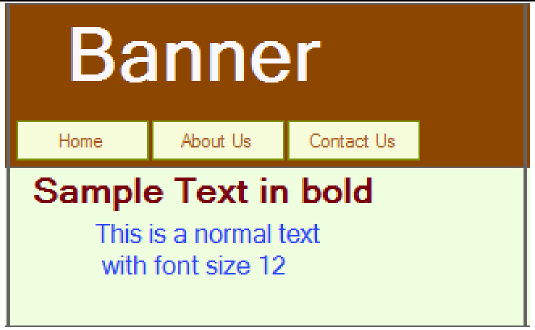


(b)

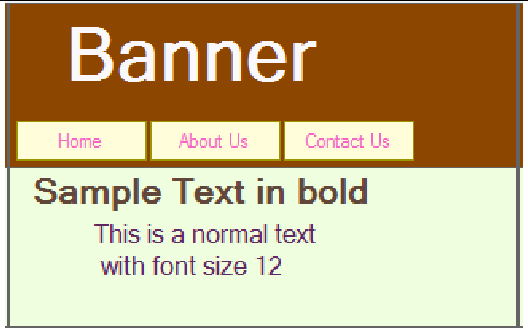


(c)

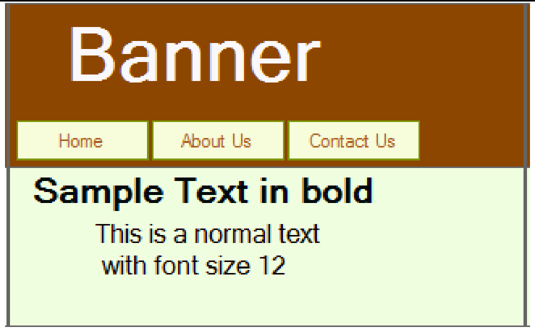
Stage 1: Evolution of banner text, button background and main text area background colours based on banner background, (a) Gen 0, (b) Gen 6 and (C) Gen 12.



(d)

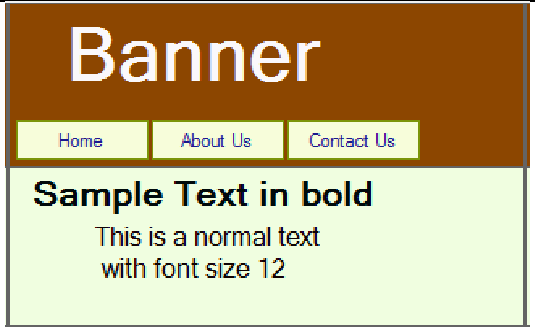


(e)

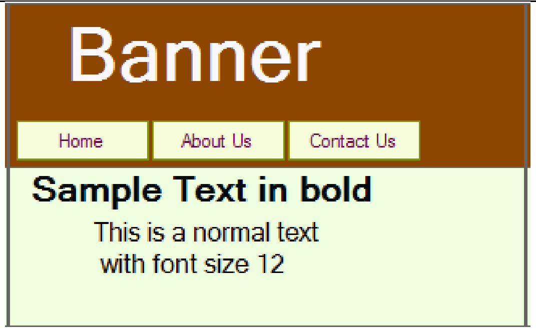


(f)

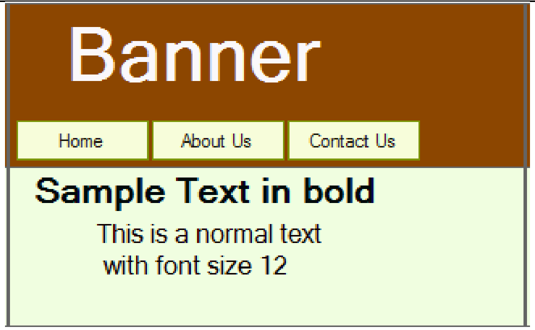
Stage 2: Evolution of bold and normal text colours based on main text area background colour, (d) Gen 0, (e) Gen 6 and (f) Gen 12.



(g)



(h)



(i)

Stage 3: Evolution of button text colours based on button background colour, (g) Gen 0, (h) Gen 6 and (i) Gen 12.

Table 13. Evolution of colour scheme generation using 3 stage evolutionary processes

3.4.4 Automatic creation of colour schemes based on climatic conditions

Cork Harbour Weather [129] (CHW) is part of a larger research and innovation platform used by the Halpin Centre[130] to explore new concepts, ideas and methodologies for enhancing situational awareness in the maritime domain. CHW provides information on current and past weather conditions and provides end-users with weather related advisories, ephemeris, phenomena and news for a geographical area centred on cork harbour on the south coast of Ireland. Using the method for developing website colours from this research, CHW has been using an automatically derived and regularly updated colour palette to dynamically change the website's colours. At regular intervals, the website colour palette is re-calculated by analysing the colour content of still images captured by weather webcams around the harbour. These images reflect the current weather conditions e.g. sunny, overcast, raining, night time, etc. providing the end-users with a visionary aid to appreciating what actual weather conditions are like in cork harbour.

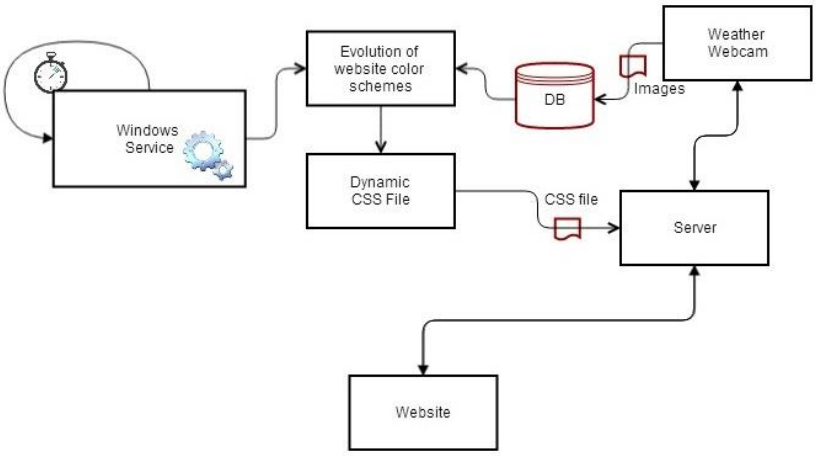


Figure 56. Dynamic colour scheme system architecture

A Windows Service is created by using the .NET framework to execute the evolutionary process for generating new colour schemes based on the latest images captured by the webcam. In every five minutes, the process of updating CSS file, i.e. to applying new colour scheme for the website design is carried out by the following steps:

1. Web camera captures live images (time-lapse) to describe weather conditions for every minute and stores the files into the database.

2. The installed Microsoft Service executes the evolutionary process for generating website colour schemes based on the latest image captured by the web camera.

3. The evolutionary process for creating a new CSS file:
   - The latest image stored in the database is taken as the reference file for creating a suitable colour scheme.
   - Vibrant colour is extracted from the selected image and used that as a main colour input.
   - A new website colour scheme, CSS file, is generated based on the vibrant colour, i.e. extracted from the latest captured image.

4. The CSS file is then uploaded into the main server that drives the weather website.

5. The CHW website automatically refreshes the whole website for every 5 minutes in order to apply the new colour scheme provided by the CSS file.

6. The whole process, from step 2 to step 5, is continued in a loop to update colour schemes based on the weather conditions from time to time.

3.5 Summary

This chapter focused on how the EC framework can be used to evolve digital landscape design and colour schemes. During the evolution of such artefacts, the process involved creating individuals, evaluating their fitness scores, selecting parent individuals and reproducing new individuals are discussed. This chapter showed the procedure of how the aesthetic measures can be used to evaluate the best fit individuals during the evaluation phase with examples. This chapter also explained the process involved in creating other features such as; creating visual representations by reading XML files, number of features and their variations in an individual, use of the network render farm and combining multiple aesthetic measures to form one final fitness measure.

4 Experiment and Results

4.1 Introduction

In this chapter experiments on evolution of landscape design and colour scheme generations were conducted to test an IGA technique and the use of aesthetic measures for finding optimal solutions.

Landscape designs: Three trials were conducted during the evaluation of landscape designs by using the IGA technique. This was to test the efficiency of EC for finding the solutions according to user preferences. Both the Information Theory and GCF aesthetic measures were also tested to determine if the user interference at the fitness evaluation phase can be replaced to evolve aesthetically pleasing landscape design.

Colour schemes: During the evaluation of colour schemes, two experiments were conducted to test the implementation of aesthetic measure in finding the appropriate colour combinations. Firstly an experiment was created to compare the methods and results obtained. This was done by using both traditional and EC ways of generating colour schemes for website design. Secondly an experiment was done in an attempt to imitate professional looking live-website colour schemes with system generated colour schemes. A list of similarities of both the colour schemes was drawn up using the obtained results.

An experimental approach was taken whereby the system was evaluated and redefined based on empirical feedback. Since the outputs of this approach are digital artefacts that aim to be aesthetically pleasing – a series of experiments with human subjects was performed.

These experiments were based on qualitative research methods that used a questionnaire and interviews as outlined below:

4.2 Experiment 1: Evolution of landscape designs using IGA

This was designed to test an IGA technique for generating landscape designs based on user preferences. The main purpose of this experiment is to show how intuitive the landscape design can be when created using EC. Images of real-world sceneries/paintings were taken from the Internet, assuming that they would be the users target sceneries. This would exhibit how an IGA technique can generate similar landscapes with relatively few simple steps. Three sets of trials were performed in this experiment as follows:

1. **Imitate natural world sceneries**: The main aim of this trial is to take real-world landscape images as (user) target sceneries, then guide the evolutionary system to generate similar ones. The four landscape sceneries taken from the Internet are desert [131], green mountains [132], wild flowers [133] and an oil painting [134]. As the evolutionary process is carried out, user fitness evaluation tests are performed on each generation by ranking the individuals that possess the desired scenery target features. The final results of these trials are shown in Table 15. Both the initial and final generations created during the evolution of the target sceneries are shown in Table 16, Table 17, Table 18 and Table 19 respectively. Generation intervals (lapse), from initial to final, were recorded while experimenting on each trial and their respective videos were uploaded on the YouTube website [135]–[138].

2. **Evolve sceneries based on 3D models**: This trial is performed to evolve sceneries that match according to the selected 3D models. At first, 3D models are inserted into the initially populated sceneries, and then the user aims to create sceneries that are based on the properties of these 3D models by using the EC framework. For example, when the 3D model of a ship is inserted into the sceneries, then the user aims to create seabed and ocean (as ships sail on the water) sceneries. IGA technique was used to rank the individuals that possessed essential features, in this the case water level during the fitness evaluation process on each generation. The results of both the initial and final generation of sceneries are shown in Table 20.

3. **Evolve art by mixing photographs and digital sceneries**: In this trial, an attempt to mix real-world photographs with evolved landscape designs was made to make them a more realistic and interesting art. For example, a plain background of a photograph can be replaced with system generated scenery using IGA techniques to transform it into a fine art, thus fulfilling users aspirations. The results of this trial are shown in Table 21.

Methods which were used in this experiment are outlined in Table 14. At the initialization phase for all three trails, the initial population was created a number of times by using *a* *random generator* in order to create diverse individuals at the initial stage. The fitness evaluation is carried out by the user, with the aim of selecting the individuals that are closer to the desired target scenery. RRWS selection is used to select and create sufficient sets of parent pairs for the reproduction process. Both crossover and mutation operations were performed with the probability rate set by the user. Newly generated individuals (offspring) were inserted back into the evolutionary system for breeding the next generation. The user ends the cycle of producing new generations when they are satisfied with the results achieved.

Phase	**Operation**	**Methods**
1	Encoding features	8-bit binary format
2	Initialization process	1. Population - 16 individuals 2. Randomized features 3. (For Trail 3) regenerated '*n*' numbers of times till the desired features are initiated.
3	Fitness function	IGA (User sets the fitness function)
4	Selection	RRWS
5	Crossover	1) Single point crossover technique 2) Probability: Set by the user
6	Mutation	1) A single point mutation technique 2) Probability: set by the user
7	Termination criterion	Until user satisfactory

Table 14. Methods used for evolution of landscape designs by using IGA technique.

4.2.1 Results

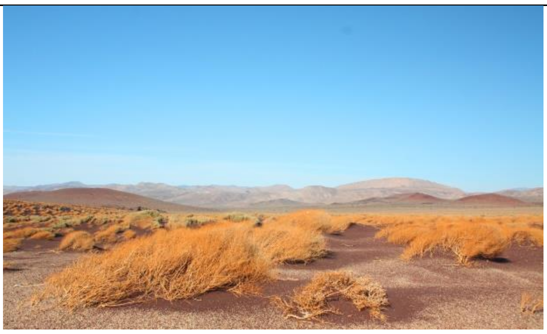
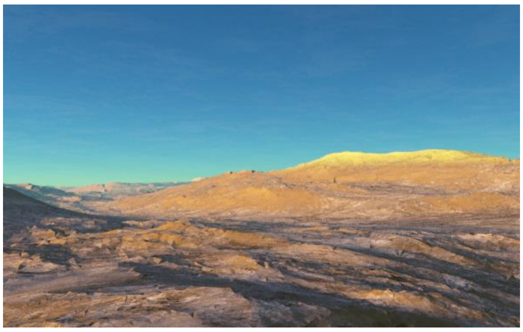
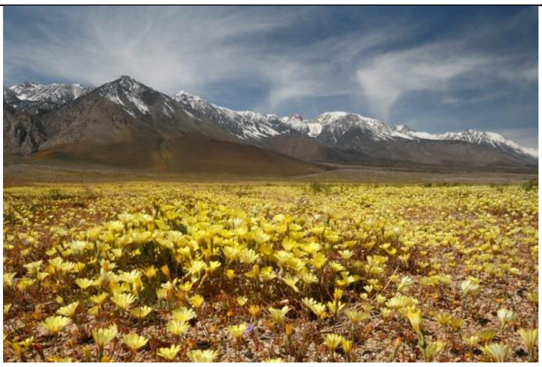
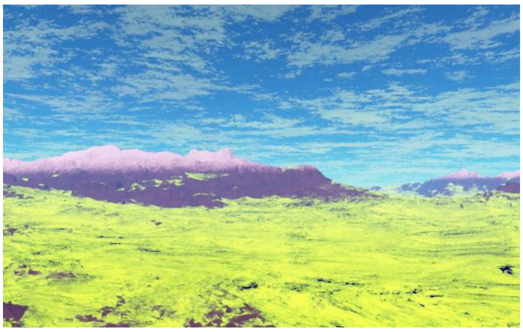
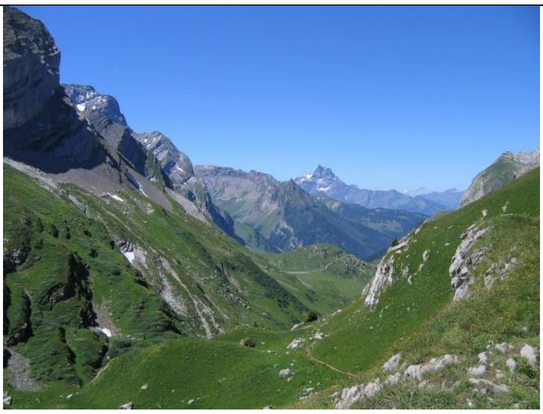
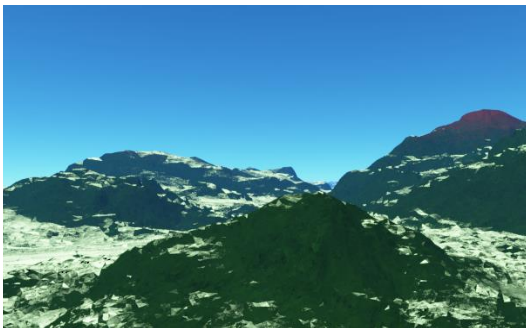
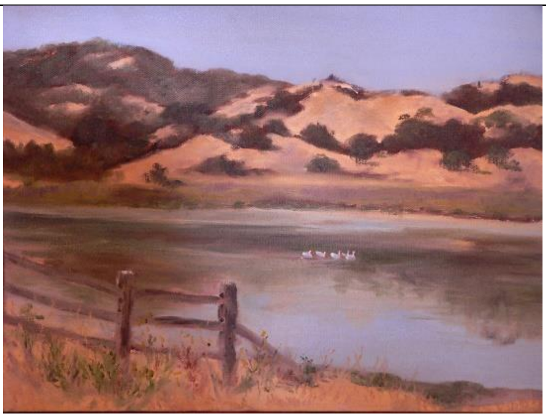
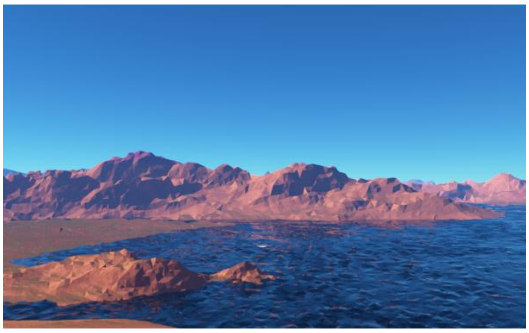
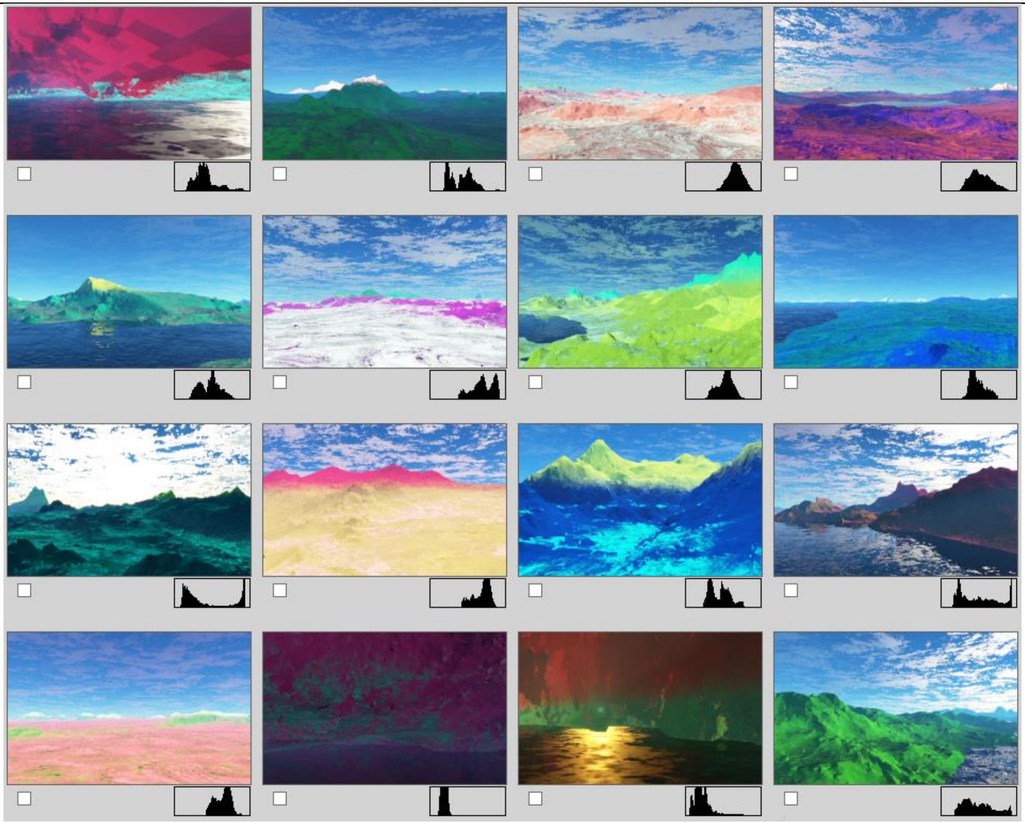
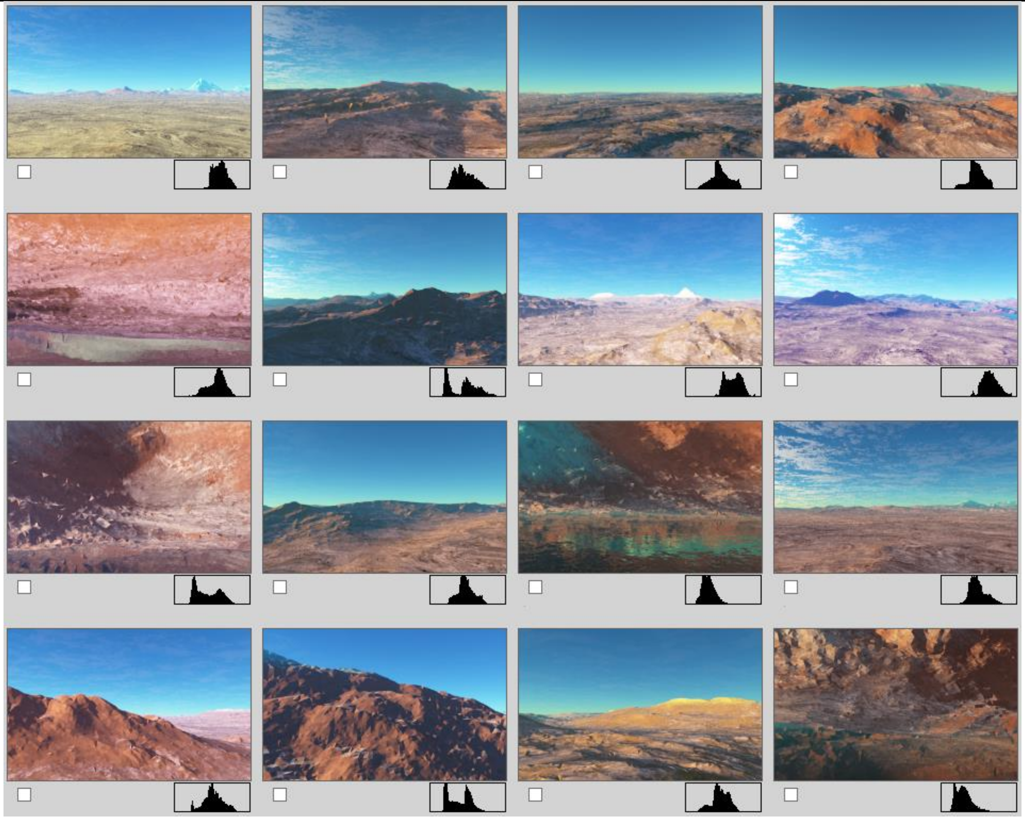
 Real-world desert scenery	 Evolved virtual-world desert scenery
 Real-world wild flowers scenery	 Evolved virtual-world wild flowers scenery
 Real-world green mountainous scenery	 Evolved virtual-world green mountainous scenery
 Marliee Ford oil Painting	 Evolved virtual-world painting

Table 15. Target sceneries (taken from a Google© search) compared with the evolved sceneries using EC.

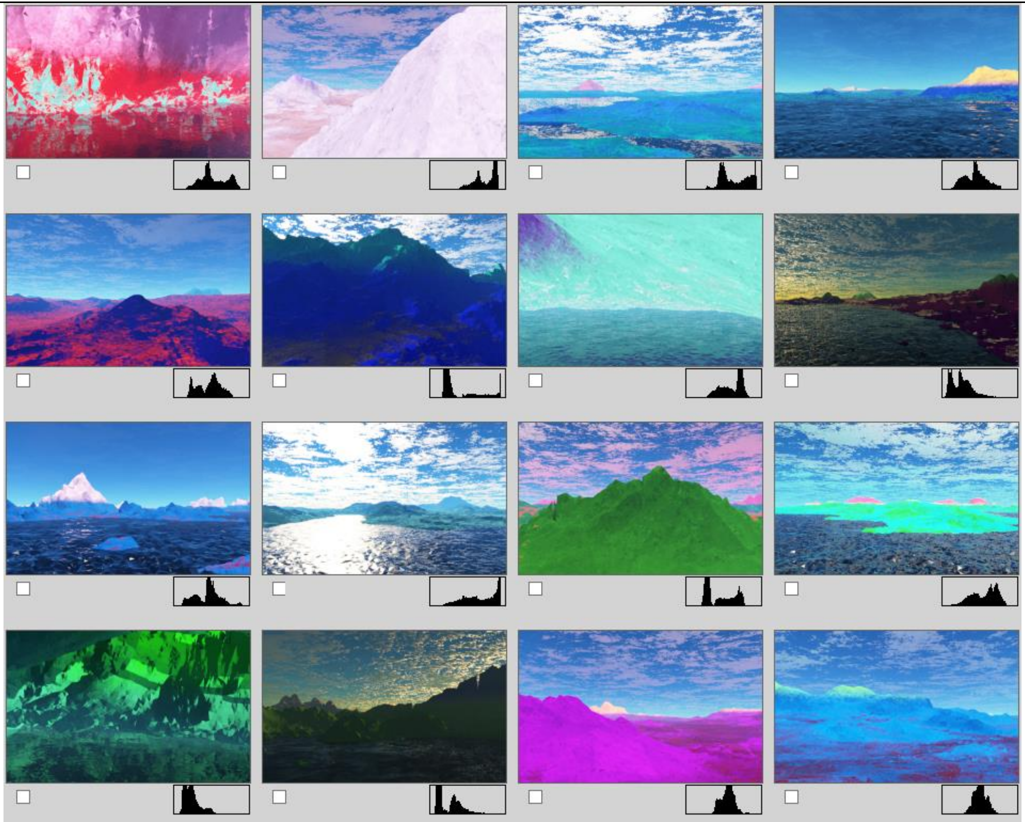


Initial population generated using randomisation of parameter values on each individuals.

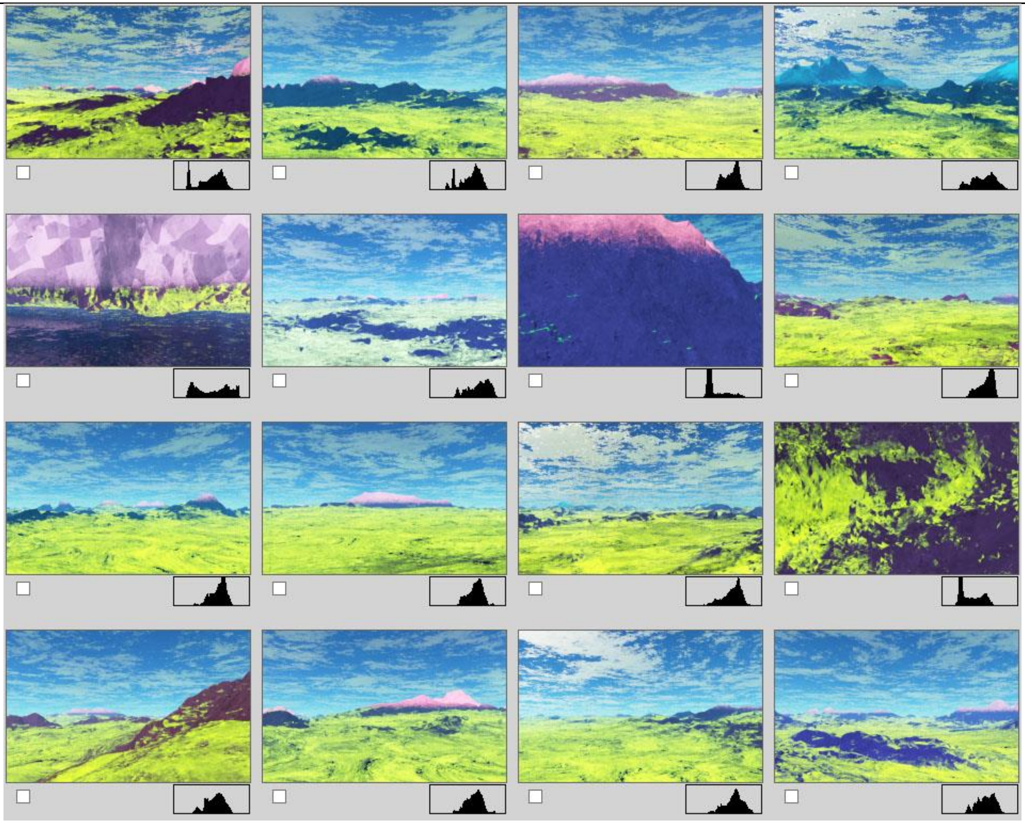


Optimized desert sceneries at 14th generation

Table 16. Comparison table between initial and final generations of landscape designs, guided by the user to evolve desert scenery.

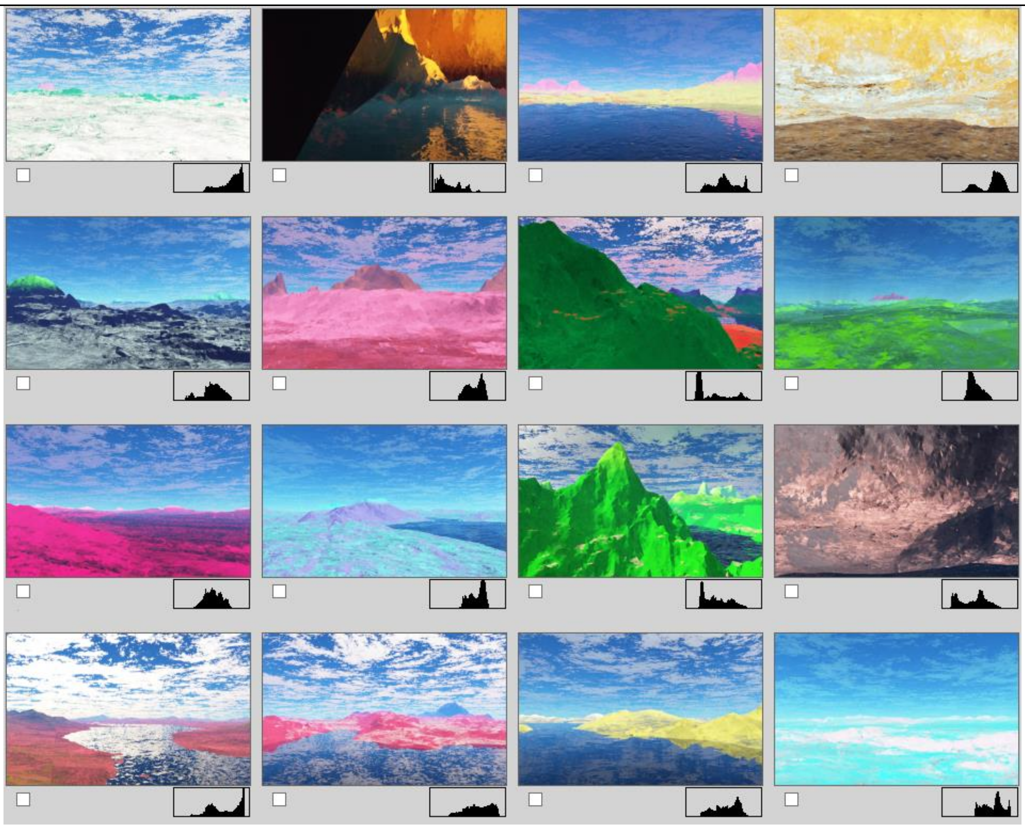


Initial population generated using randomisation process.

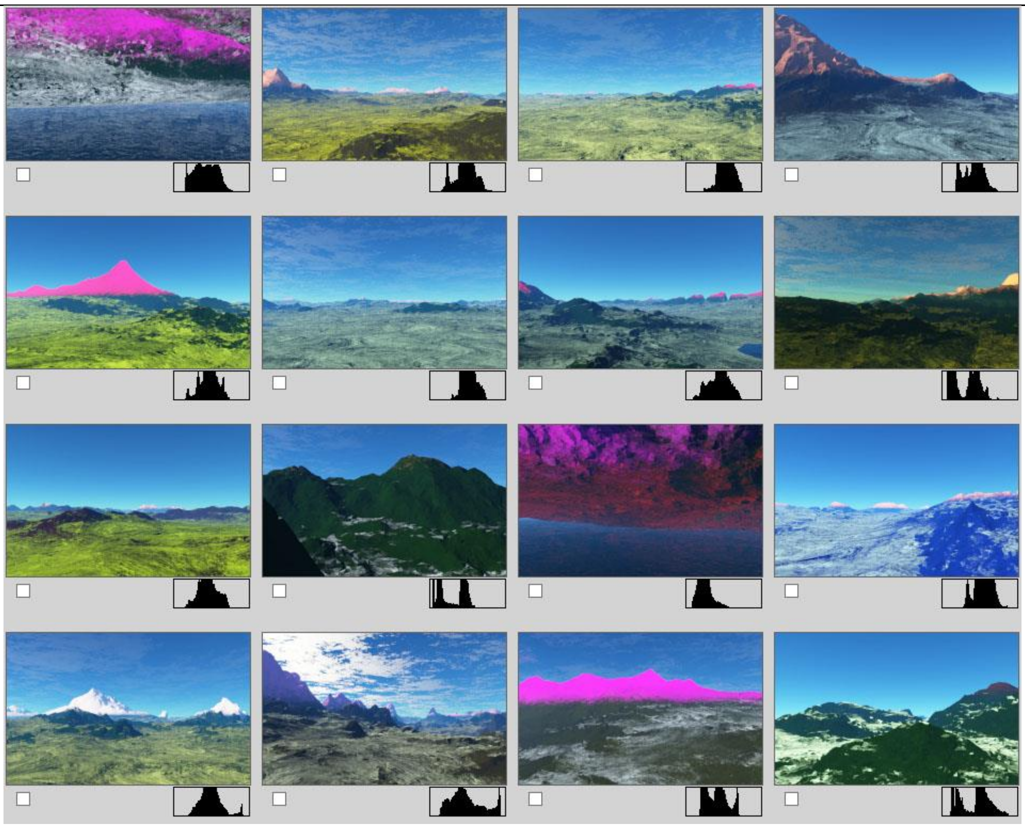


The Final generation of the wild flower sceneries using IGA technique.

Table 17. Comparison table shows both initial and final generations of wild flower scenery.



Randomly initialised population for the evolution of green mountains using IGA technique.



Evolved green mountains sceneries at the 18th generation.

Table 18. Comparison table showing both initial and final population of green mountains sceneries.

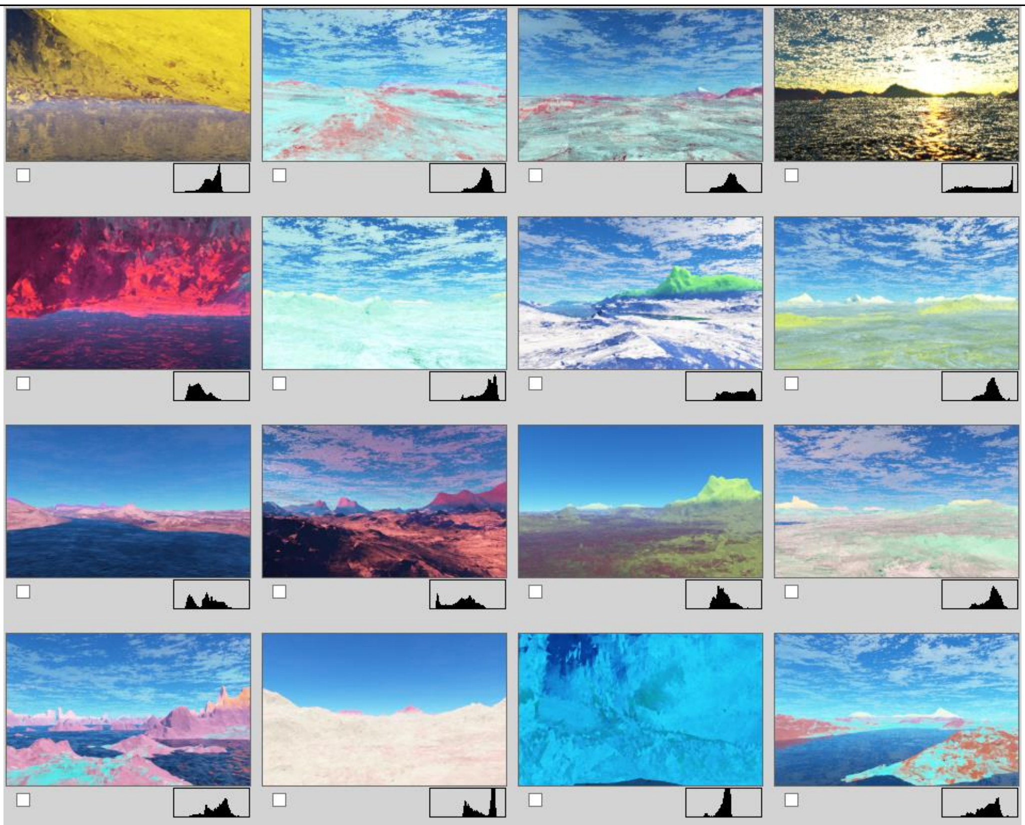
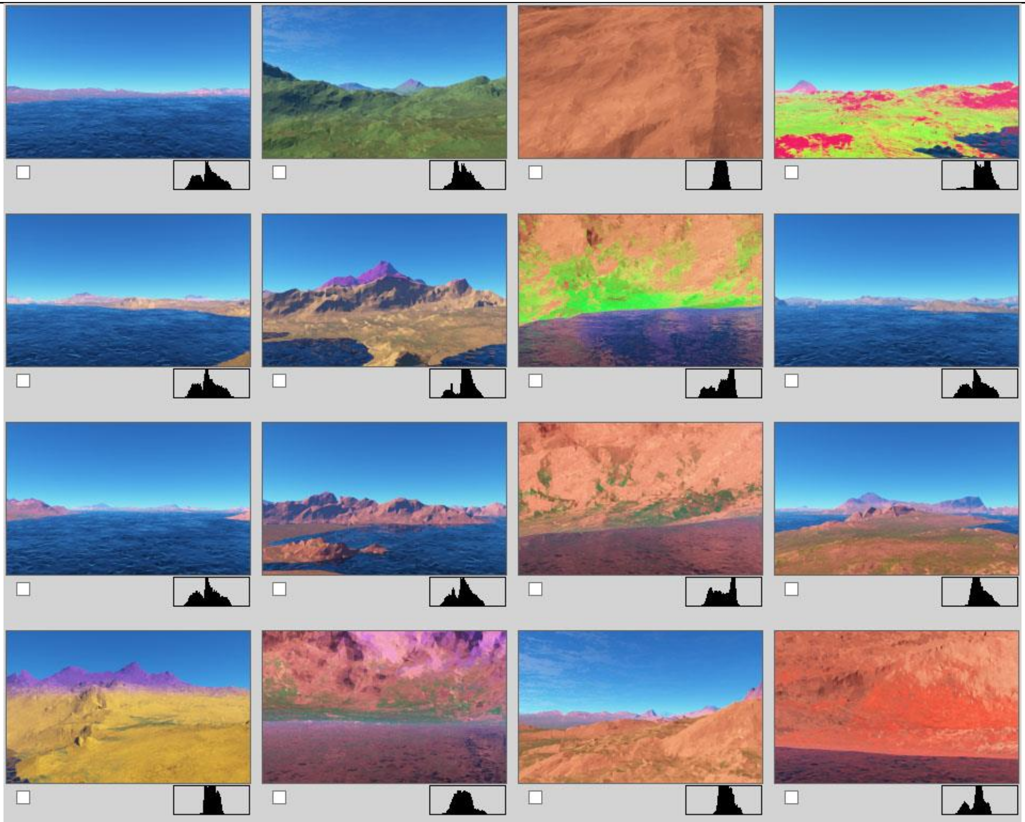
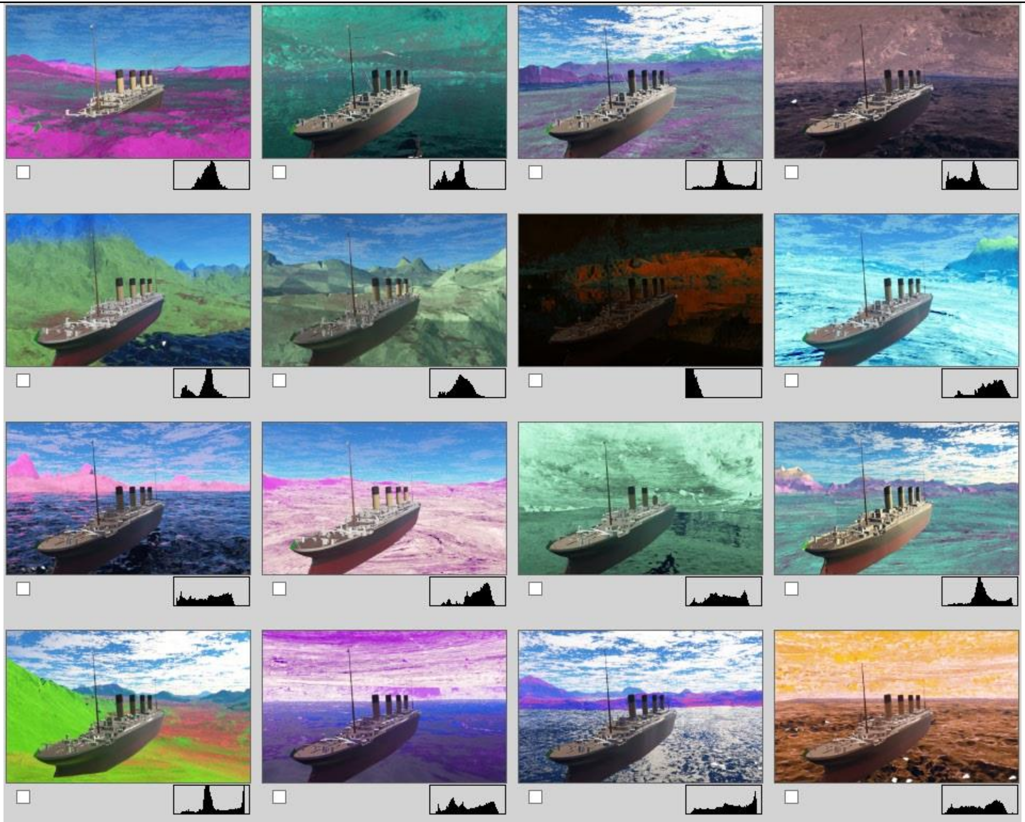
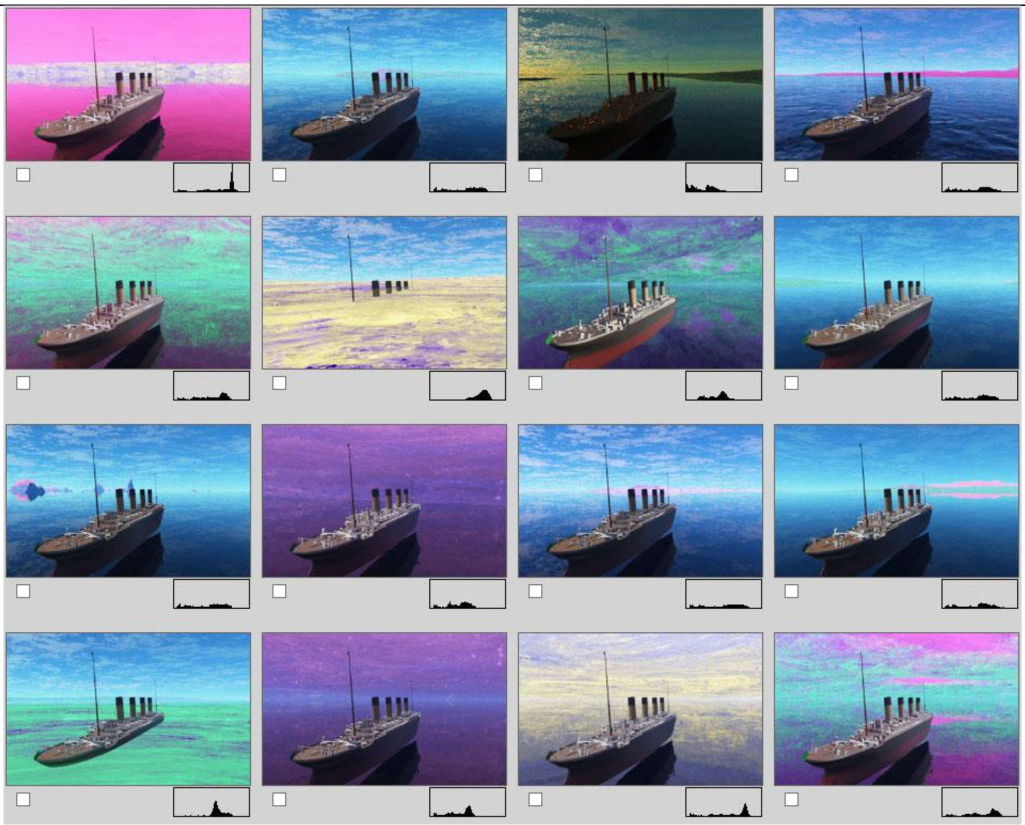
 Initial population generated for the evolution of a painting scenery.
 11th generation showing the final results of evolved painting sceneries.

Table 19. Comparison table showing both initial and final generation of evolving painting scenery.

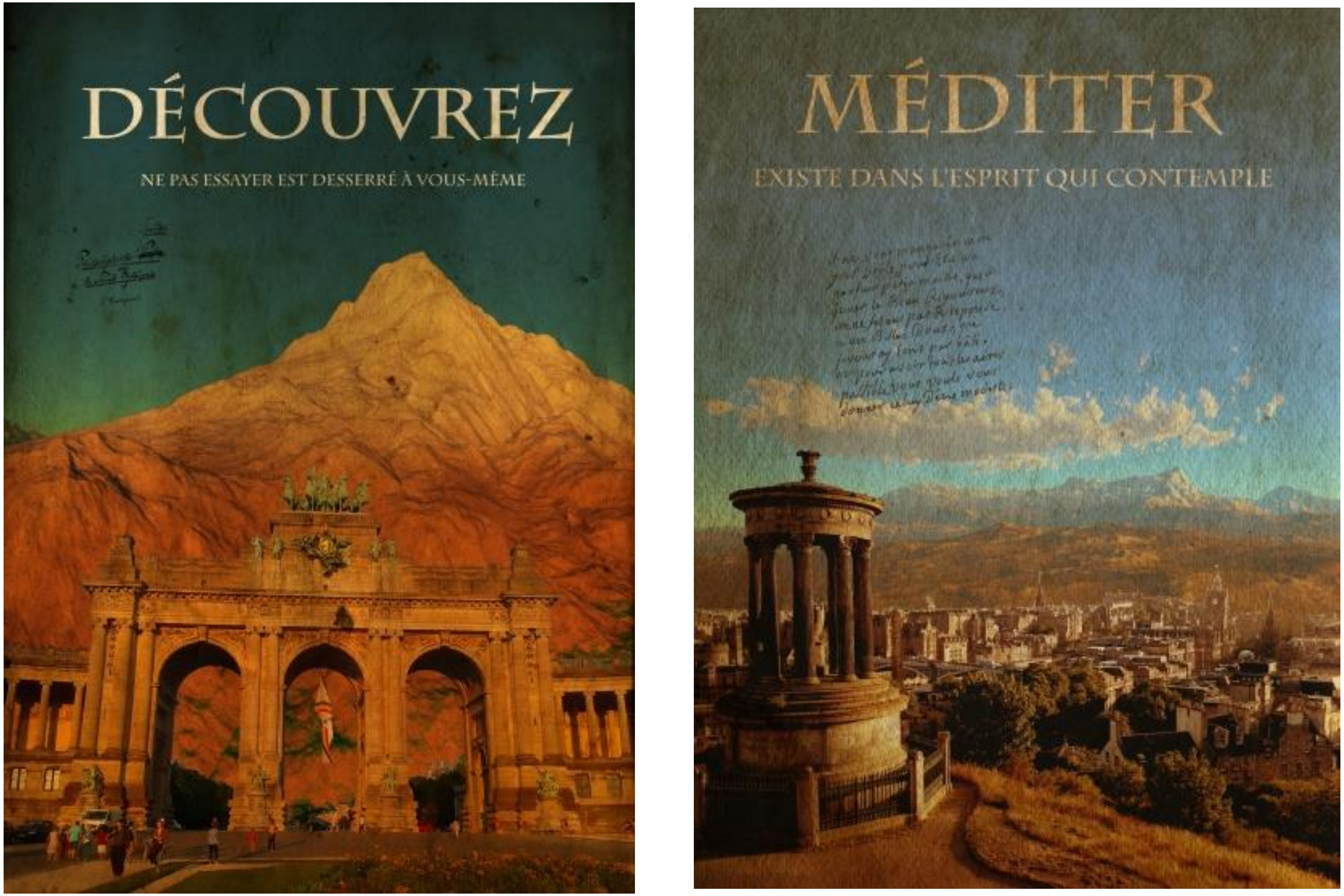


Initial population of sceneries with inserted 3D model of a ship.

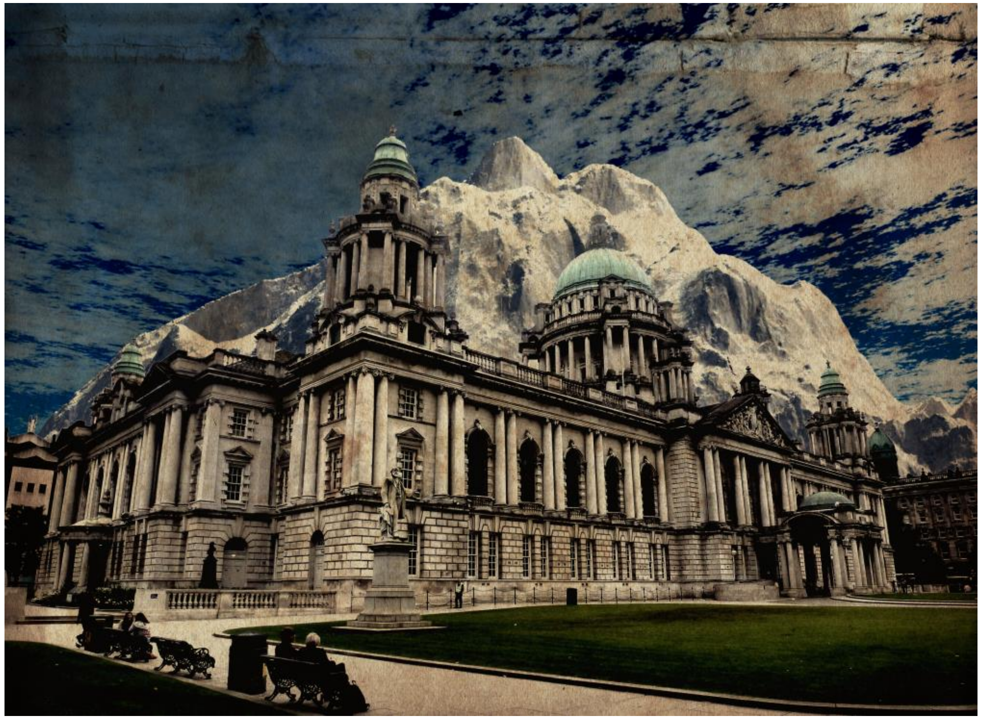


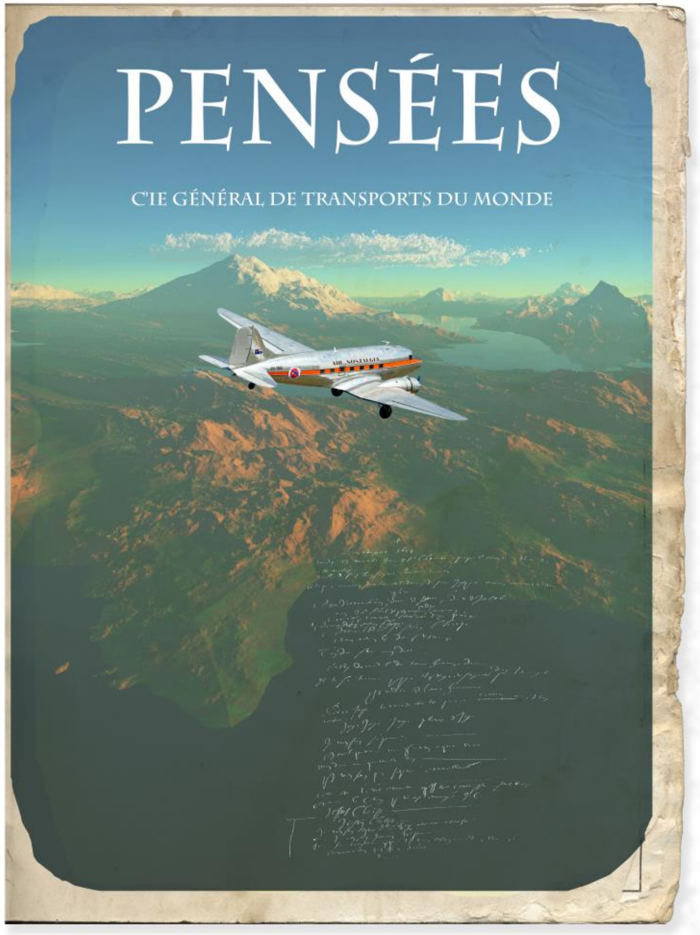
14th generation of evolved sceneries matching the 3D model.

Table 20. Initial and final generation for the evolution of a scenery matching the 3D model.


DÉCOUVREZ
NE PAS ESSAYER EST DESSERRÉ À VOUS-MÊME
MÉDITER
EXISTE DANS L'ESPRIT QUI CONTEMPLE

Background scenery generated using IGA mixed with real-world photographs.





Background scenery generated from this research is mixed with real-world photograph (left) and a photograph of an aeroplane is inserted into matching scenery.

Table 21. The evolution of art – examples of evolved sceneries using IGA technique that match both real-world photographs and 3D models.

From the results obtained in this experiment, it is apparent that the IGA technique used in the evolution of landscape designs is capable of generating a large range of target sceneries. This is without requiring any type of skill from the user, such as the prerequisite skills of modelling, and the use of learning materials or practice of tutorials for scenery generation software, etc. The groups which can benefit by using the EC framework developed from this research are considered to be as follows:

- **Game developers:** Graphic game designers can build an initial stage of an imaginary world with a relatively few simple steps by using the EC framework and can then later sculpt this into a virtual reality world by adding 3D models, or any other suitable objects that matching their requirements.

- **Artists:** Artists can build and visualise their imaginary world before starting to paint the scenery. The final results obtained by using these research methods, could be helpful; giving a guideline for their finished product with the natural effects such as, sun rays, lightning, shadows, mixing texture colours etc.

- **Movie graphic designers:** Many movie graphic designers use Terragen software for the creation of virtual reality worlds [54]. By using this EC framework to generate landscape designs, it would help them to start the initial stage of the sceneries very quickly and mould them later on according to the film sets.

- **Terragen users:** Users which includes the developers, of the Terragen software agreed that research into the IGA technique, to evolve landscape designs is an interesting approach for the scene development saving time while creating landscapes [139]. Some of the comments made are as follows:

    a. "*It looks like an interesting approach to scene development.*" - Oshyan (Planetside senior staff)

    b. "*Looks very interesting*" – Kadri (senior member)

c. "*Looks like a useful way of quickly setting up a scene for further tweaking*" – Cyphyr (senior member)

There are, however, a few drawbacks which were identified while performing these experiments using IGA technique and are as follows:

1. **User fatigue:** The user may get tired evaluating all sixteen landscape designs in each generation against the target scenery, throughout the experiment.

2. **Delay in processing time:** The Terragen render engine needs high processing power to transform the TGD files into images, especially where images contain reflective surfaces.

Even though user fatigue is a common drawback in IGA method; this research still used this technique to find the possibilities of creating a virtual world through evolutionary algorithms. Since the results were encouraging this could lead to a new path for other researchers/developers to use IGA in the creation of virtual reality worlds. In the later experiments, to counter user fatigue, aesthetic measures were implemented to replace the user altogether; computationally ranking individuals based on their aesthetic scores. To improve the generation rendering time, a network render farm was used, to increase the processing power, thus speeding up the rendering of TGD files into images.

4.3 Experiment 2: Evolution of landscape designs using Information theory

Both quantitative and qualitative approaches are followed to test the efficiency of Information Theory as an aesthetic fitness measure to generate landscape designs that possess interesting information. In the quantitative approach, data is collected by the EC framework. This is set to create 25 iterations of the generations. The qualitative analysis is performed using the obtained results, by surveying how many of the volunteers are attracted to the landscape designs that are rated by Information Theory.

GAs methods used in this experiment are outlined in Table 22. The initialization process is carried out by randomizing features on each of the sixteen individuals to generate an initial population as shown in Table 23. By using Equation 13, the Information Theory fitness test is performed on these individuals to obtain their fitness value. Based on their scores, ranking is done programmatically by assigning the lowest fitness valued individual as Rank 1, the next lowest as Rank 2, and so on. In the selection phasethe RRWS selection methodod is used to select the required number of parent pairs for the mating process. Both crossover and mutation operators are executed to form the next generation individuals, i.e. Generation 1. Subsequently, Generation 1 is fed into the evolutionary process as an initial population to generate the next generation, i.e. Generation 2, then Generation 3, and so on. The whole process is repeated until the final generation is achieved, which is the 25^{in}generation for this experiment as shown in Table 23.

Phase	**Operation**	**Methods**
1	Encoding features	8-bit binary format
2	Initialization process	• Population - 16 individuals • Randomized features
3	Fitness function	Information Theory (As an aesthetic measure)
4	Selection	RRWS
5	Crossover	• Single point crossover technique • Probability: 0.8 (80%)
6	Mutation	• Single point mutation technique • Probability: 0.6 (60%)
7	Termination point	25 generations (decided by the end-user)

Table 22. Methods used for evolution of landscape designs by using Information Theory as an aesthetic fitness function.

4.3.1 Results

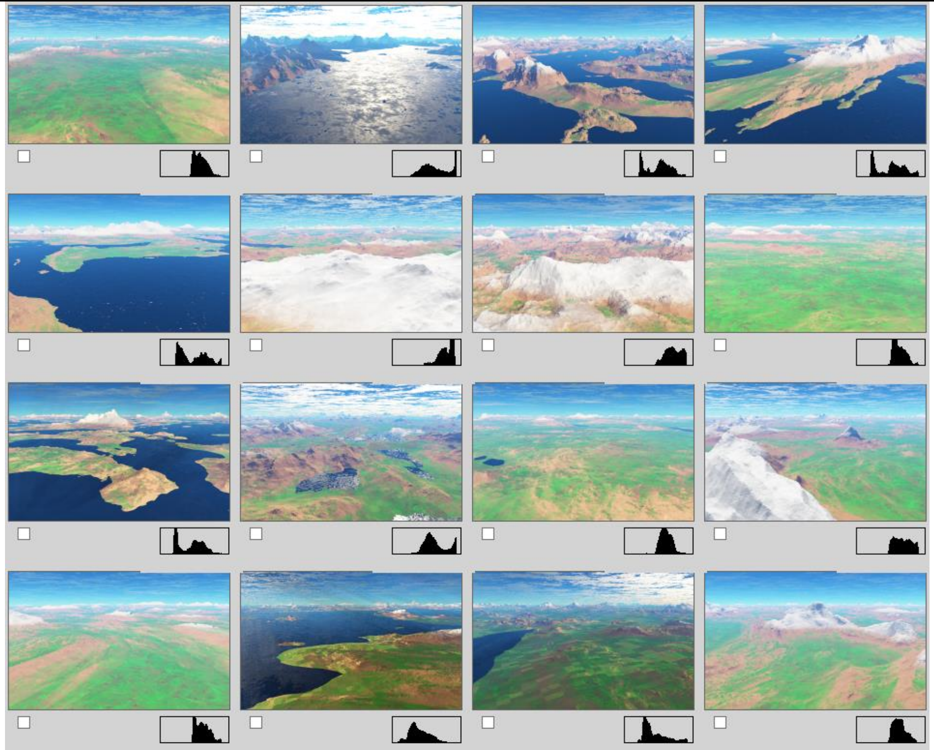
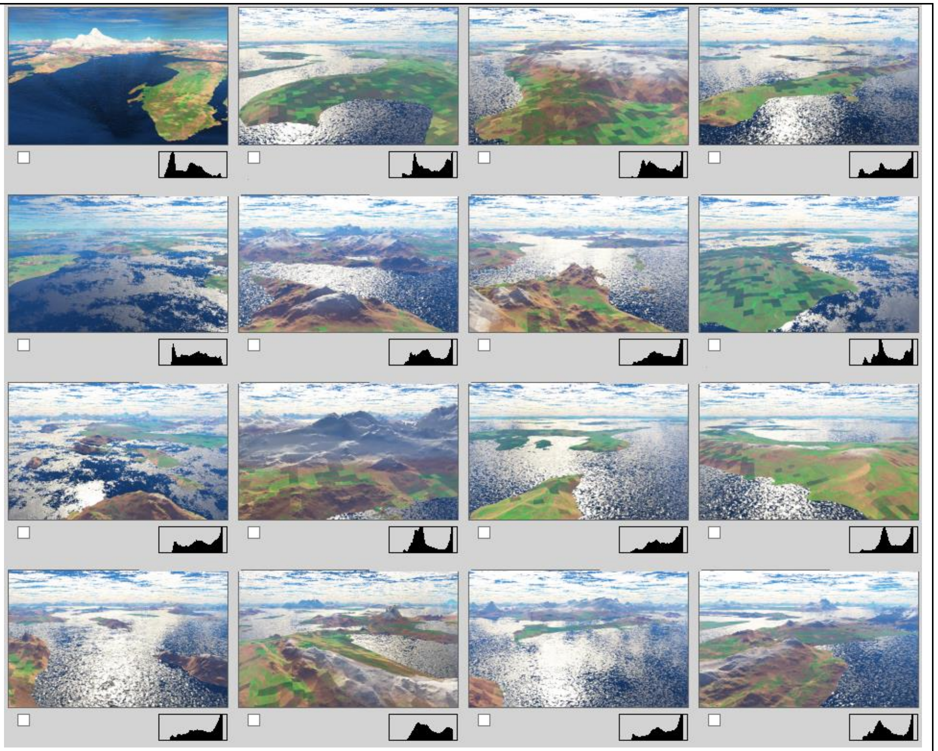
	
Initial population showing random featured individuals.	The final generation of individuals evolved by using the Information Theory fitness function.

Table 23. A comparison table showing both initial and final generation of landscape designs evolved using Information theory as an aesthetic measure.

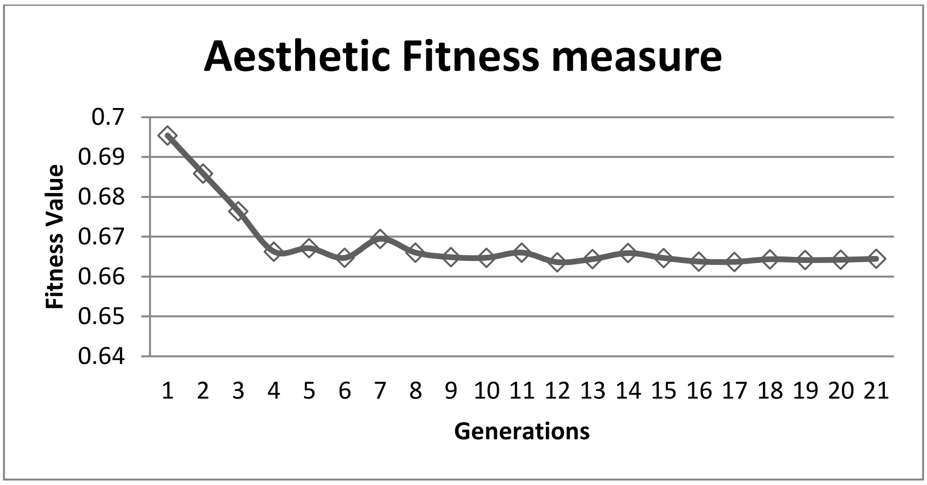


Figure 57. Sample GA run showing aesthetic fitness measure reducing to a minimal value.

Based on the average fitness values from initial to final generations as shown in figure 57, it can be seen clearly how GAs managed to lower the fitness values, from one generation to the next, thus bringing more information to the individuals (landscape designs).

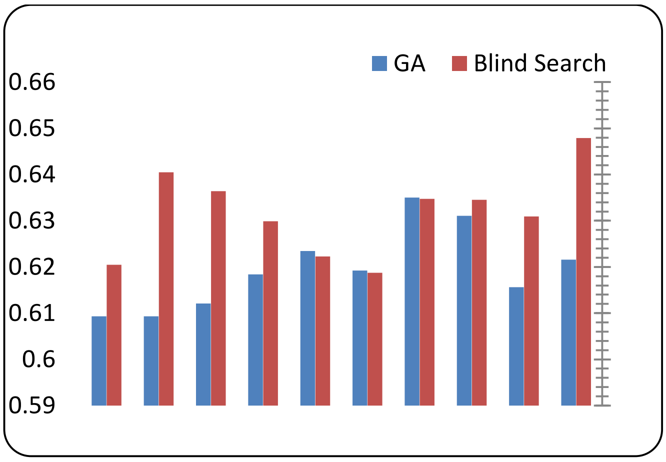
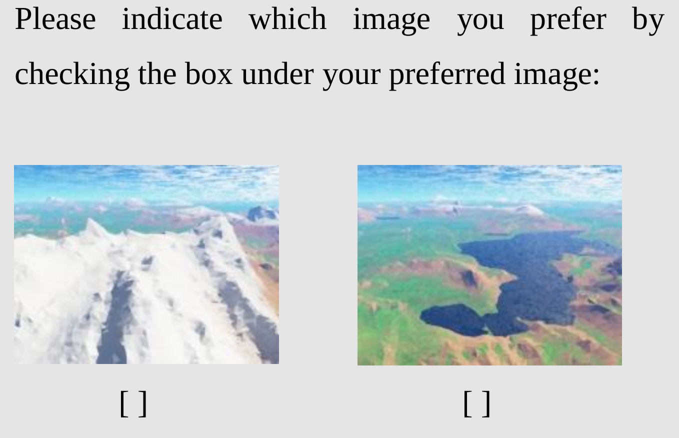


Figure 58. Comparison of best results produced via GA versus blind random search.

	GA Search	Blind Search
Mean	0.62001	0.63164
Variance	9E-05	8.53E-05
Observations	10	10
Hypothesized Mean Difference	0	
df	18	
t Stat	-2.77758	
P(T<=t) one-tail	0.006209	
t Critical one-tail	1.734064	
P(T<=t) two-tail	0.012419	
t Critical two-tail	2.100922	

Table 24. Hypothesis test results for blind search versus GA

When a comparison is made between the initial and final population of individuals as shown in Table 23, it illustrates that Information Theory can evolve aesthetically pleasing landscape designs automatically without user intervention during the fitness evaluation phase. To prove this, a survey of users based on statistical sign test was conducted. The 42 users, via an electronic questionnaire, were required to pick the most aesthetically pleasing landscape design from 10 paired selections of images. One of the images represented a high fitness score and the other represented a low fitness score, as shown in figure 59. Users were unaware of the fitness scores, nor were they aware of the sample placement. The samples were drawn randomly with equal probability of being placed on either the left or right during the survey.



Please indicate which image you prefer by checking the box under your preferred image:

[ ] [ ]

Figure 59. Survey sample showing images, one of which has a high fitness score and one of which has a low fitness score.

Non-Parametric sign test analysis shows that 95% of respondents to the questionnaire preferred the images classified with high fitness by the aesthetic fitness measure. The results were also encouraging for the use of computational aesthetic fitness measures as 72% of human evaluators preferred those images rated high by the Information theory.

4.4 Experiment 3: Evolution of landscape designs using GCF

To test the efficiency of the GCF aesthetic measure in the evolution of landscape designs, two types of tests were performed. The first test is to check the effect of the GCF fitness measure on landscape designs with default parameter values. Based on the observations and suggestion made on Test 1 results, Test 2 is performed by keeping some of the parameter values related to the landscape designs at low level in order to test the effectiveness of the fitness measure on the remaining parameters. The main reason to edit parameter ranges is to reduce the effect of cloud reflection over water as seen in the final generation of landscape design in Table 27.

4.4.1 Test 1: GCF Aesthetic Test

An automatic evolutionary process of evolving landscape designs using GCF as the fitness function is set to 25 iterations of generations. GA methods used in this test are shown in Table 26. At the initialisation phase, parameter values of each individual are randomly generated, within their specified range, as shown in Table 25. At the fitness evaluation phase in each generation, the GCF function identifies the landscape designs that possess good contrast levels and ranks the top three individuals accordingly by using equation 10. Selection of parent pairs is done by using RRWS. A new group of individuals, Generation 1, are generated after the crossover and mutation operations are performed. The EC framework runs in a loop to form Generation 2, Generation 3, and so on until Generation 25 is generated. Both the initial and final generation is shown in Table 27. Test 1 generation lapse is recorded and its video uploaded onto YouTube website [140].

Parameter	Minimum value	Maximum value
Sun elevation	0	90
Sun is heading	0	360
Terrain feature scale	2000	20000
Displacement spike limit	0	1
Cloud altitude	5000	20000
Cloud propagation mix	0	1
Cloud density	0	0.05
Cloud depth	0	100
Water wave scales	0	100
Water roughness	0	0.3
Water level	-800	500
Sand texture colour (RGB)	0	255
Rock texture colour (RGB)	0	255
Grass texture colour (RGB)	0	255

Table 25. Evolutionary parameter values range set for Test 1: the use of GCF aesthetic measure in the evolution of landscape designs.

Phase	Operation	Methods
1	Encoding features	8-bit binary format
2	Initialization process	4. Population - 16 individuals 5. Randomized features
3	Fitness function	Information Theory (As an aesthetic measure)
4	Selection	RRWS
5	Crossover	3) Single point crossover technique 4) Probability: 0.8 (80%)
6	Mutation	3) Single point mutation technique 4) Probability: 0.6 (60%)
7	Termination point	25 generations

Table 26. Methods used for evolution of landscape designs by using Information Theory as an aesthetic fitness function.

4.4.2 Results

Even though the GCF fitness function works on the pixel luminance of a greyscale image, it is observed that during the evolution of (coloured) landscape designs GAs managed to find the right colour combinations of RGB values to match the contrast levels produced by GCF function. As noted, in the final generation every landscape design contains high water levels and cloud reflections as this tends to give a high GCF score. The chart in Figure 60 shows that there is an emerging trend of higher average fitness scores over successive generations, which shows that the evolutionary search mechanism is operating as expected in the fitness function. Mutation occasionally disrupts this upward trend to ensure an element of diversity remains in the population.

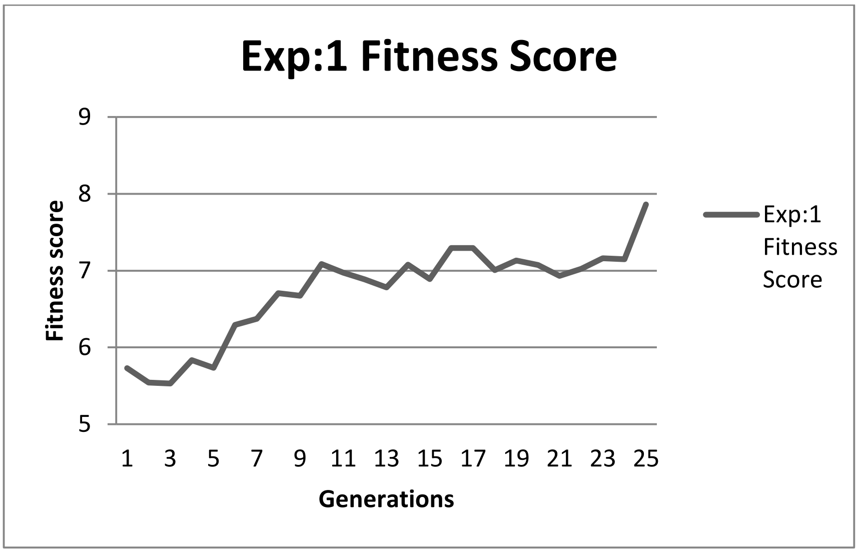


Figure 60. Experiment 1 – Fitness graph.

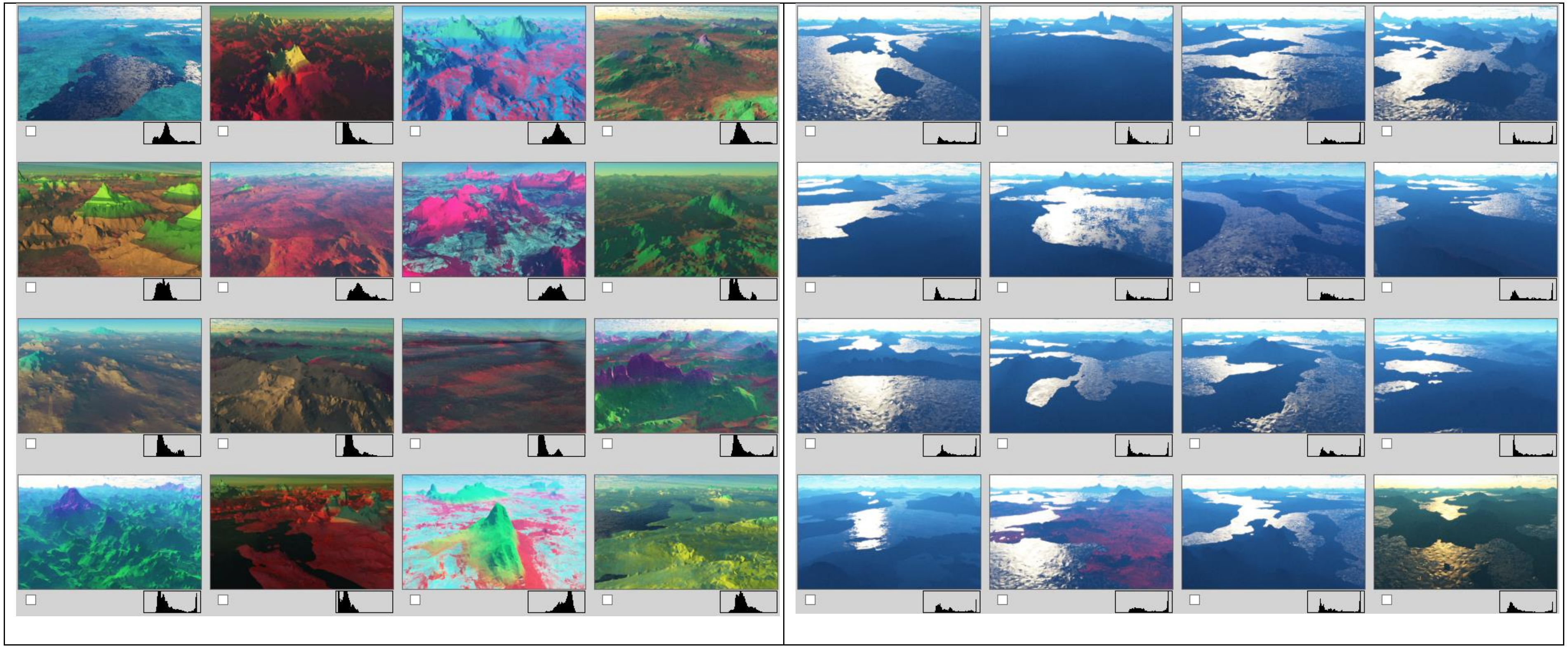


Table 27. Initial (left) and final (right) generation of landscape designs in Test 1: Evolution of landscape designs using GCF aesthetic fitness measure.

4.4.3 Test 2: GCF Aesthetic Test with Reduced Water and Clouds

Test 2 has the same goal as Test 1, except in this case the effect of clouds and water are reduced and terrain texture colours are kept as constants in order to force the GCF fitness measure to act on the remaining parameters of the landscape designs. This was done after feedback from experts suggested that the reflective properties of water can bias the contrast factor to high values. Methods used in this test are shown in Table 26 and the adjusted parameter values range is shown in Table 28. It can be seen that the water levels, cloud depth and density values are reduced when compared with Test 1 parameter values range as shown in Table 25.

Parameter	Min	Max
Sun elevation	0	90
Sun heading	0	360
Terrain height	2000	20000
Terrain spikes	0	1
Cloud altitude	5000	20000
Cloud propagation mix	0	1
Cloud density	0	0.01
Cloud depth	0	10
Water waves	0	100
Water roughness	0	0.3
Water level	-1200	-500
Terrain textures (RGB)	Static	

Table 28. Adjusted parameter values range for Test 2: the use of GCF aesthetic measure in the evolution of landscape designs.

4.4.4 Results

During the evolutionary process it is observed that the parameters which were kept at low range maintained low profile, allowing testing of the effectiveness of GCF measure on other parameters. A comparison table of both the initial and final generation is shown in Table 29. From the achieved results, it can be seen that the algorithm automatically directs the evolution of landscapes towards a set of parameters that represent balanced compositions. Interestingly, the generated landscapes which are best-ranked tend to have fairly naturalistic composition compared to the original generation; without any input from the user. The generation lapse video is also uploaded to the YouTube website [142].

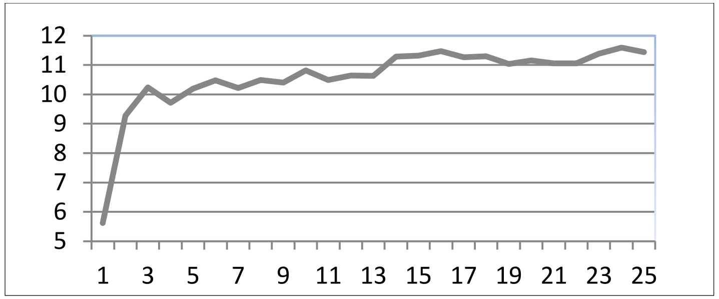


Figure 61. Experiment 2 – Fitness graph.

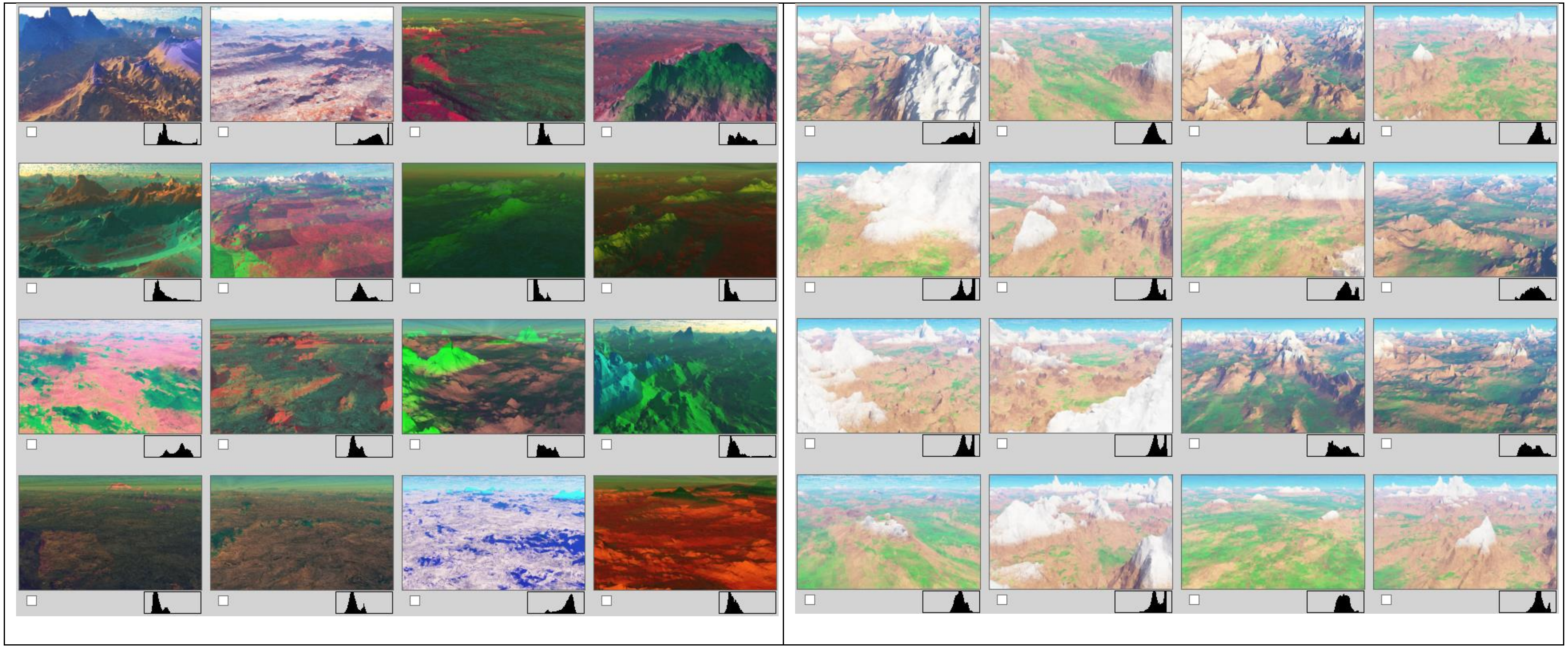


Table 29. A comparison table of both the initial (left) and final (right) generation of landscape designs evolved using GCF aesthetic test with lowered parameter values.

4.5 Experiment 4 – Compare methods and results obtained between the user and the system generated colour schemes

In this experiment, both quantitative and qualitative analysis is performed on the 52 users to test the efficiency of GAs generating website colour schemes. First the 52 colour schemes, created both by the users and the system are collected. A comparison is then made by performing two types of analysis to see whose colour schemes are more preferred by the end-users.

4.5.1 Creation of colour schemes for website designs

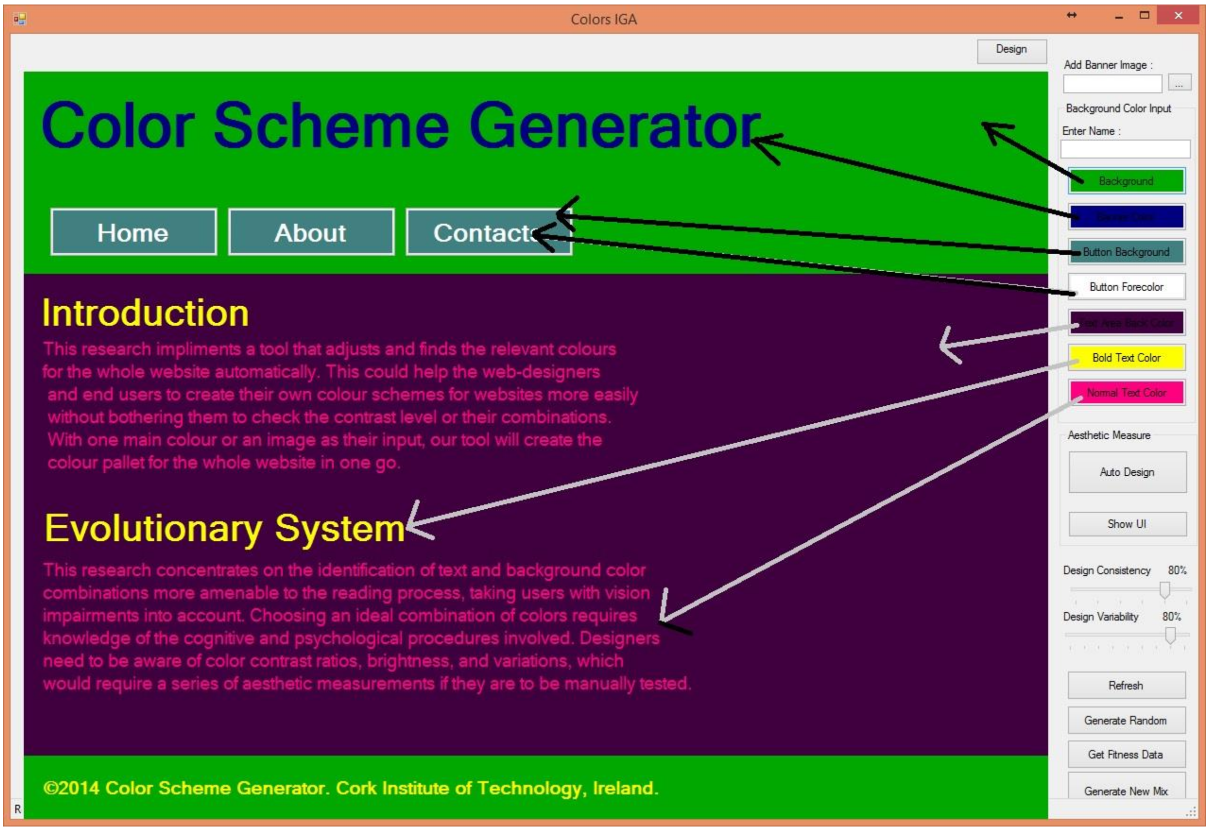
The users were given the task to apply their favourite colours onto a website design by using GUI as shown in figure 62. The users aim was to create aesthetically pleasing colour schemes, based on the conditions that the selected colour combinations should make the text aesthetically pleasing to look at and easy to read. To start the experiment the user selects their favourite colour for the banner background, then finds the remaining colours of the website accordingly. During this process the GUI helps the user by displaying the selected colours onto the website instantly, giving an impression of the final product. The user can update the selected colours any number of times before finalising the test.

Soon after the user finishes the test, based on the user's main colour, i.e. banner background colour, the system will take over the controls and execute GAs method to find the remaining colours of the website using computational aesthetic measures as their main fitness function. The methods used by GAs in this experiment are outlined in Table 30.

At the initialisation phase, tournament selection is performed to select the best fit individuals for creating the initial population. At the fitness evaluation phase, fitness scores of each individual are calculated by using Equation 29 which ranks them accordingly. An example of ranking colour combinations is shown in Table 12. The RRWS selection method is used in the selection phase. Both crossover and mutation operators, in the reproductive phase, generate a new population. EC framework runs until a total of 12 new generations are populated and one of the best fit individual's (template) colour schemes in the final generation is selected and applied to the website design.

Phase	Operation	Methods
1	Encoding features	8-bit binary format
2	Initialization process	1) Population size - 12 individuals (website templates) 2) Tournament selection
3	Fitness function	1) CCR – to maintain colour proper contrast levels 2) BD – to maintain proper brightness difference levels 3) CD – to maintain proper colour difference levels
4	Selection	RRWS
5	Crossover	5) Multi-point crossover technique 6) Probability: 0.8 (80%)
6	Mutation	5) Multi-point mutation technique 6) Probability: 0.8 (80%)
7	Termination point	12 generations

Table 30. Methods of GAs used in the evolution of website colour scheme generation.



Color Scheme Generator

Introduction

This research impliments a tool that adjusts and finds the relevant colours for the whole website automatically. This could help the web-designers and end users to create their own colour schemes for websites more easily without bothering them to check the contrast level or their combinations. With one main colour or an image as their input, our tool will create the colour pallet for the whole website in one go.

Evolutionary System

This research concentrates on the identification of text and background color combinations more amenable to the reading process, taking users with vision impairments into account. Choosing an ideal combination of colors requires knowledge of the cognitive and psychological procedures involved. Designers need to be aware of color contrast ratios, brightness, and variations, which would require a series of aesthetic measurements if they are to be manually tested.

©2014 Color Scheme Generator. Cork Institute of Technology, Ireland.

Add Banner Image :

Background Color Input

Enter Name :

Aesthetic Measure

Design Consistency 80%

Design Variability 80%

Figure 62. Interface showing how to select colours for creating a colour scheme.

The average time taken by the end-user to fill seven colours on a website was 2 minutes 45 seconds, whereas the system found colour schemes in less than 30 seconds. It is also observed that, while the end-user applying colour to the website design, they were confused and reselected different colours number of times before finalising the test. When the actual numbers of colours are increased, which is possible for a real website design, there is a high probability that users might face a more challenging situation which would result in increased time taken to find the right colour combinations.

4.5.2 Analysis 1: A survey – preference of colour scheme generated between the system and user

A total of 52 users participated in the creation of colour schemes for website designs. A survey is performed using an interactive interface as shown in figure 64, to let the user decide which colour scheme, either created by themselves or by the system, is better in terms of aesthetically pleasing to look at and easy to read the text. Of the survey group, 57% agreed that they would prefer the system generated colour scheme more than their *own* creation of colour schemes. However, there is scope for user bias; where users may tend to like their colours against the system generated colours. Moreover, the colours selected by the user are not guaranteed to aesthetically pleasing to other users because there is lack of aesthetic tests performed; which are most recommended by W3C. To find this out, Analysis 2 is conducted to see if there can be any difference found in the obtained results.

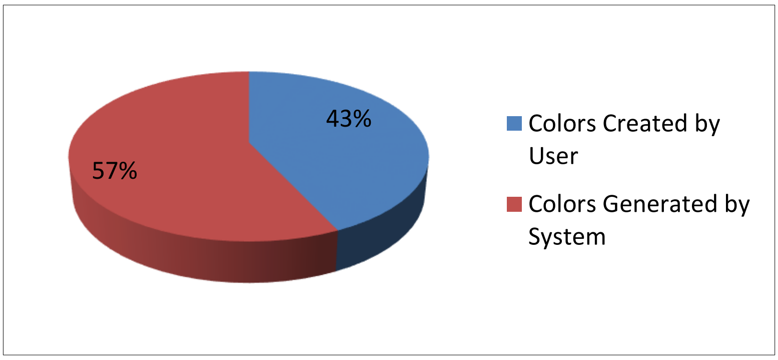
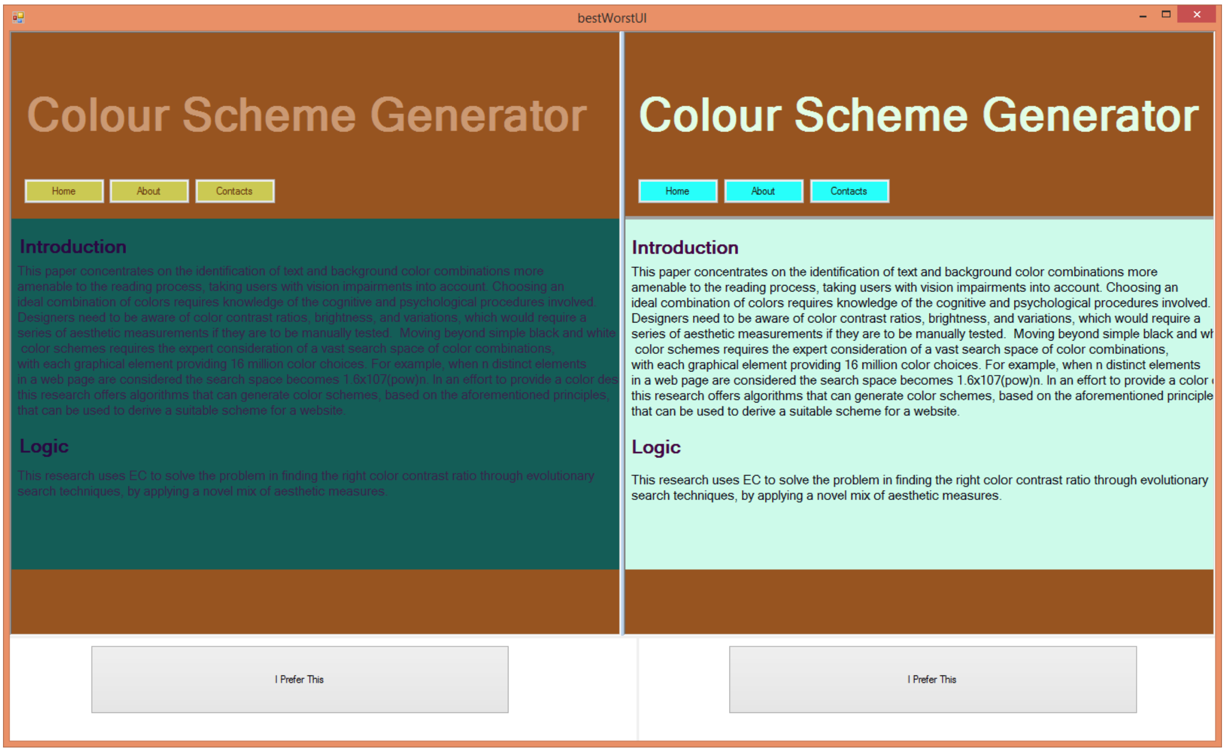


Figure 63. Most selected website colour schemes between the system and user in Analysis 1.



Introduction

This paper concentrates on the identification of text and background color combinations more
amenable to the reading process, taking users with vision impairments into account. Choosing an
ideal combination of colors requires knowledge of the cognitive and psychological procedures involved.
Designers need to be aware of color contrast ratios, brightness, and variations, which would require a
series of aesthetic measurements if they are to be manually tested. Moving beyond simple black and white
color schemes requires the expert consideration of a vast search space of color combinations,
with each graphical element providing 16 million color choices. For example, when n distinct elements
in a web page are considered the search space becomes 1.6x107(pow)n. In an effort to provide a color des
this research offers algorithms that can generate color schemes, based on the aforementioned principles,
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Logic

This research uses EC to solve the problem in finding the right color contrast ratio through evolutionary search techniques, by applying a novel mix of aesthetic measures.

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Figure 64. Comparison Interface test between System and User websites.

4.5.3 Analysis 2: A survey – preference of colour scheme generated between the system and 52 users

To counter user bias in selecting their own colour scheme, as observed in the Analysis 1, an another comparison test is performed allowing them to select the preferred colour scheme of the interface as shown in figure 64. This time, the placement of the colour scheme generated by the system or the users is unknown. Even the sample pair shown to the user is randomly selected from the DB by the program itself. The users were requested to select a sample (from between 10 to 30 samples) that they think are aesthetically pleasing and are easy to read text.

Of the 52 users, 69% of them selected the colour schemes that are generated by the system and the remaining 31% were selected for the user created colour schemes, as shown in figure 65.

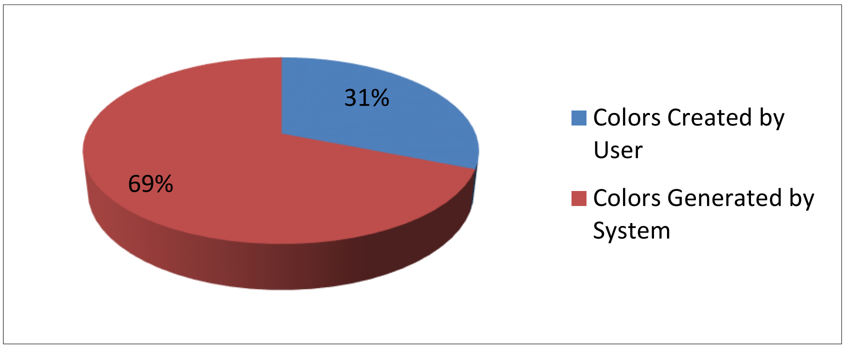


Figure 65. Most selected website colour scheme between the system and user in Analysis 2.

For each colour scheme generated by the system GAs maintained the fitness levels, as recommended by W3C as shown in Table 31. This shows the effectiveness of the EC since it is upheld in all four of these aesthetic tests for all the 52 samples.

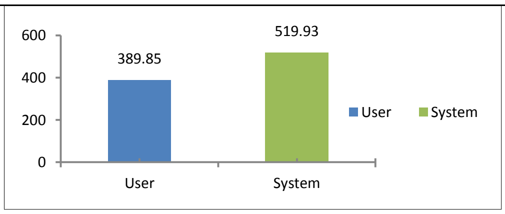
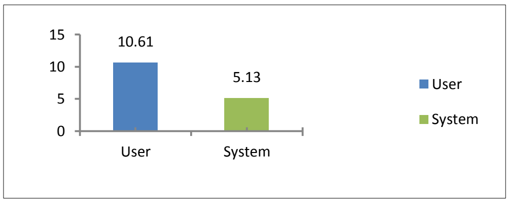
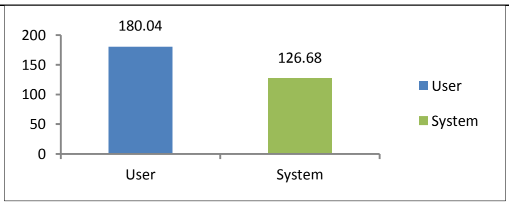
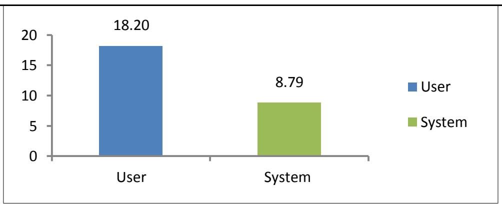
 CD fitness value (greater than 500)	 CCR fitness value for smaller text (nearly equals to 4.5:1)
 BD fitness value (greater than 125)	 CCR fitness value for bigger text (nearly equals to 7:1)

Table 31. Mean values of aesthetic measures calculated out of 52 samples generated by the system.

4.6 Experiment 5 – compare colour schemes between live-websites and system generated designs

In this experiment, a comparison test is performed between the existing website colour schemes and the system generated colour schemes. The main aim of this test is to check the capabilities of this research in evolving colour schemes compared to skilful artistic web designer colour schemes. Live-websites, chosen in this experiment are, Stanford University [142], the CERC conference [143], AIB's internet banking [144] and Ryanair [145]. The processes followed are:

1. Capture a screenshot of a live website (main page).
2. Extract the main banner colour.
3. Input the extracted colour as background colour in EC framework interface as shown in the figure 62.
4. Trigger *Auto Design* button to start the application for evolving colour scheme based on the background colour.
5. Repeat step 4 a number of times till satisfied with the colour scheme evolved.

The GAs process followed in this experiment is similar to Experiment 4 as shown in Table 30. Except in this case, the whole experiment was re-run (including initialisation phase) until satisfied with the end results achieved. This is due to the nature of the EC, where the results obtained on each run will have different outcomes. Even though each outcome satisfies the aesthetic measures fitness test, this experiment was re-run until a similar colour scheme, compared with the live-website colour scheme, are generated. End user can end the process when the results are even more aesthetically pleasing than to the existing website colour schemes. Results of all four website samples achieved are shown in Table 32 and their live recorded video was uploaded to the YouTube website [146].

4.6.1 Results

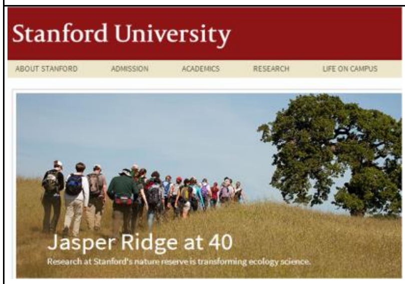
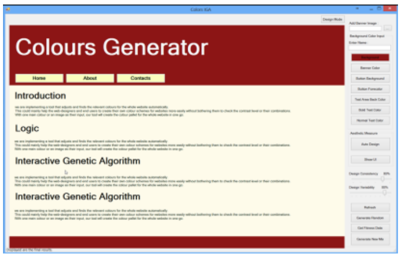
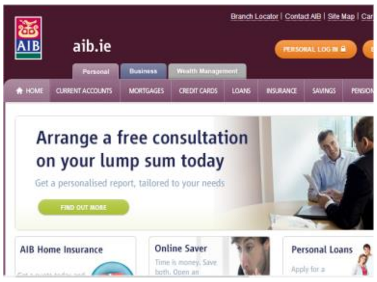
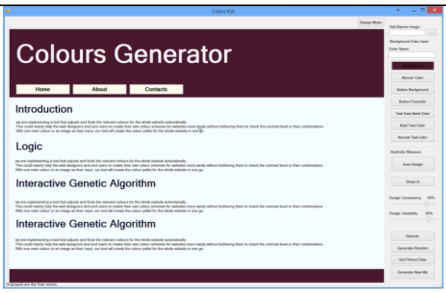
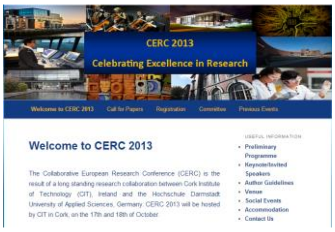
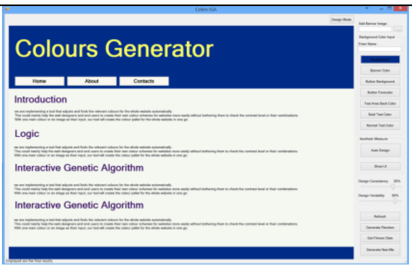
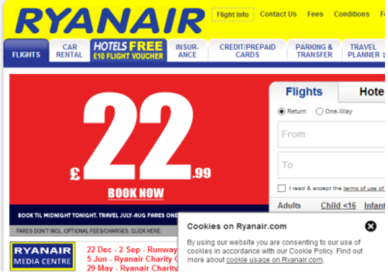
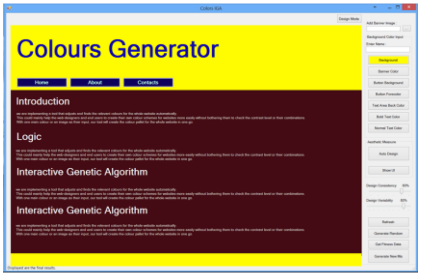
Live website Vs Auto generated colour schemes	Runs
 	2
 	6
 	5
 	4

Table 32. Comparison of colour schemes between the live websites, and the system generated.

As can be seen in the results, Table 32, similar colour combinations are obtained, when comparing the website and system generated colours. For example,

- Stanford University's main page contains dark red background colour with white coloured banner text and light golden coloured buttons with black colour button text, which are the same colour combinations that can be seen in the system generated colour scheme.

- On Ryanair website, yellow coloured banner background with blue coloured banner text and blue coloured button/tabs with white colour button text, are again similar colour combinations found in the corresponding system generated colour scheme.

- Both the CERC conference and AIB internet banking websites background and banner colours are also matched to the corresponding system generated colour combinations.

The creation of a suitable colour palette while preparing a colour scheme for a website design may take many human hours of trial and error to find the optimal solution. But from these experiment's results, EC framework proves that it not only competes with an experienced, website designer-generated, professional looking colour scheme, but can also find the optimised solution within a minute.

4.7 Summary

In this chapter, by using the EC framework developed from this research, various experiments and trials were conducted and the results were examined. In the evolution of landscape designs, based on IGA technique three types of trials were performed and proved that EC can help end-users to achieve their goals in different scenarios. By using Information Theory and GCF aesthetic measures, it is also proven that aesthetically pleasing landscape designs can be evolved automatically without the need for user involvement during the fitness evaluation tests. Similarly, in the evolution of website colour scheme generation, the results proved that system generated colour schemes are preferable when compared with human generated colour schemes. Additionally, in the experiment comparing the live-websites with system generated colour schemes it is observed that solutions given by EC can match professional website graphic designer colour schemes.

5 Conclusion

The primary objective of this research was to develop a prototype to find an optimal solution to problems that exist in the field of digital visual artefacts. Creation of digital sceneries for virtual worlds and colour schemes for website designs were the two artefacts investigated in this research. It is deduced from a review of the literature that the existing tools and research methods do not expose the problems faced by the end-users while building such artefacts. Most of the software available for the creating of digital sceneries for games, virtual worlds or the arts requires a significant amount of time and manual input. Similarly, for creating harmonious colour schemes for website design, the tools that exist are mostly user dependent for selection, mixing or applying colours. Finding proper colour combinations by using manual tools would not only increase human hours, but also affect the human aesthetics such as readability and harmonious tests. To address such problems in both fields, this research developed an EC framework that allows end-users to automatically build landscape designs and create harmonious colour schemes effortlessly.

Based on GAs method, a single EC framework was built implementing both IGA technique and the use of aesthetic measures to automate the evolutionary process. Based on existing EC frameworks, user feedback, interviews, and advice from professionals, a set of new tools were developed in order to help end-users during the evolutionary process. (See Section 3.2). Several other applications and GUI's were developed to speed up; the rendering process, automate colour scheme generations based on images, and to perform several experiments and trials.

The results obtained in this research shows that the GAs can solve problems related to the usability of terrain and colour scheme generation methods. GAs are useful in search related problems for finding an optimised solution. In this case, terrain generation software, Terragen, has more than 800 floating parameter values that are automatically adjusted by GAs to obtain a desired landscape design. For the colour scheme generation process, $n * (1.6 * 10^7)^n$ different colours are searched by GAs when creating a colour scheme that satisfies the necessary aesthetic measures test. This research could become a case study for GAs related research methods and be also helpful to other researchers who are working with digital artefacts.

5.1 Research Outputs

This research has developed and produced,

1. An Application Program Interface (API) for Terragen to read, edit and render the TGD files using command line arguments. This API will allow researchers, designers, modellers, and others who are working with Terragen software to automate the transformation of TGD files into images without opening its GUI.

2. A prototype of the terrain generator, ATGS, to allow end-users to rapidly build landscape designs. This helps any professional or non-professional users to generate imaginary worlds and make them into digital sceneries without needing to learn any specialised skills. This prototype can also be useful for many researchers who work on EC to know how IGA technique works, especially in the field of digital art; such as creating sceneries for games, virtual worlds, and movies.

3. A prototype for using aesthetic measures for generating/evolving landscape designs. Information theory and GCF aesthetic measures were implemented to automate the whole evolution process. This approach can become a case study for other researchers who work on developing digital visual artefacts by using EC.

4. A prototype of a virtual network farm for rendering TGD files generated by Terragen. This is to accelerate the evolutionary process by speeding up the rendering of TGD files into images. There are no official render farms provided by the Planetside software group or any open source code available for Terragen users. This application would be helpful to other researchers (who require multi-computer processing power), programmers (who want to learn/develop networking code), modellers, graphic designers, and non-professional users who work with Terragen software looking to render their files more quickly. By using this application, it is very easy to setup a local or a Web-based network render farm by adding any number of client machines.

5. An API for Terragen software. This is to help non-professional end-users, especially those who are not experienced using scenery generating software for building a number of varied sceneries effortlessly by adjusting just ten parameters. The included

parameters are terrain (displacement height and spike limit), cloud (depth, density and propagation mix), water (height, wave scales and roughness), and sun (direction and elevation). The rest of the parameters are kept constant while creating a TGD file.

6. A prototype of an EC framework for the evolution of landscape designs using both GAs and IGA techniques. During the evolutionary process, this framework is capable of running the following techniques when required:

    - **GA mode**: GA mode is turned on automatically when aesthetic measures and *auto-run* options are selected by the end-user.
    - **IGA Mode**: If none of the above two options are selected, then the framework changes to IGA mode waiting for the commands from end-users to evaluate fitness test on each individual.

    This framework is also capable of normalizing aesthetic measures to form a final fitness function, when more than one aesthetic measure is selected. There were other optional tools implemented in the framework in order to help end-users while the evolutionary process is taking place (See Section 3.2). This framework can be useful to other researchers as a guideline for creating a similar framework according to their EC projects.

7. A prototype for extracting vibrant colours from an image. This is used to find the base (main) colour of a website design before identifying the remaining colours in a palette. This application can become a useful colour tool for many artists, graphic/website designers and end-users who work on colour theory projects.

8. A prototype for generating colour schemes of a website design based on climatic conditions. This application could become a useful tool for a weather broadcast website to alert its visitors of climatic conditions in the form of colour schemes. This application could also be useful as a colour scheme generator for many website designers to quickly generate a colour theme based on company logos and images. End-users could also benefit from this tool for personalising their own schemes based on images or favourite colours.

9. A prototype of an EC framework for the evolution of website colour schemes using both GAs and IGA techniques. As mentioned in point 7, GAs and IGA mode can be turned on and off based on user selections. The aesthetic measures used in this study are CCR, CD and BD to make sure a readability test is performed on each colour combination in each generation during the evolutionary process is taking place. This application can be useful for both professional and non-professional website designers while building colour schemes.

5.2 Future Work

5.2.1 In the Evolution of digital landscapes

This research is capable of generating digital landscape sceneries by using evolutionary methods. But, during the course of the study, it is observed that the methods, tools and techniques used in this research can be improved to increase the performance of the EC framework. They are as follows:

1. To increase the number of parameters involved in the evolutionary process. As already mentioned in the Section 3.3.1 that only thirteen parameters were used on each template for initial testing and the rest of them were kept at constant values. But, by processing more parameters throughout the evolutionary search could increase the diversity of the population, thus giving a wider variety of results to the end-user.

2. To increase the number of aesthetic measures used for evaluating images generated by Terragen software. For initial tests, only two aesthetic measures were implemented in this research. Based on the review of the literature, it is found that a number of other aesthetic measures could also be used to evaluate individuals for producing more aesthetically pleasing landscape designs through the evolutionary search. Aesthetic measures include Benford’s Law, Ross & Rolf -bell curve (R&R), Fractal dimension [86], etc.

3. To increase the number of 3D models placed into the sceneries generated by this

research. Only nine models were inserted into the EC framework for the initial testing. Increasing the variety models, such as the types of grass, trees, buildings, roads, etc. could bring virtual reality into the scenery.

5.2.2 In the Evolution of website colour schemes

This research is capable of finding proper colour combinations between any two colours. By using this functionality, this study can be further developed to build various tools that could help end-users who work on colour theory projects:

1. **Logos generation tool:** A tool to identify contrast ratio levels, colour differences and to check brightness levels would be ideal for logo generation software. Such a tool can be easily modified by extending this research to generate various colour palettes used during the creation of logos.

2. **Colour wheels:** Graphic designers and artists mainly use colour wheels while generating colour themes for various digital visual artefacts. An application developed from this research to find opposite colours can be further modified to develop interactive colour wheels based on end-user favourite colours.

3. **Colour scheme generation for various digital artefacts:** This research was focused on preparing colour schemes for website designs. But, this research output can easily be extended to form digital artefacts colour scheme tools such as; for desktop applications, GUI’s, mobile operating systems, clothing designs, and any other applications that rely on colour combinations.

During the course of this research, it has been identified that there are a number of other tools, techniques, and aesthetic measures, available in the literature that could be added into the existing EC framework. They are:

1. To increase the population size. In the present research, only templates with groups of twelve were used in the evolutionary search. Increasing the population group size will increase the diversity of the population, bringing a wider variety of output.

2. To improve the harmonious colour combinations by adding more aesthetic measures. Such as CIELAB[114] Fairchild (1998) to measure the colour differences, a natural colour system (NCS) [147] a logical colour notation system, etc.

3. To increase the number of colours used in a template. This research used seven colours in a colour palette while generating colour schemes for website design. This number can easily be increased by adding colours for links, visited links, shadows - heading text, frame border, image and mouse hover - text, buttons, etc.

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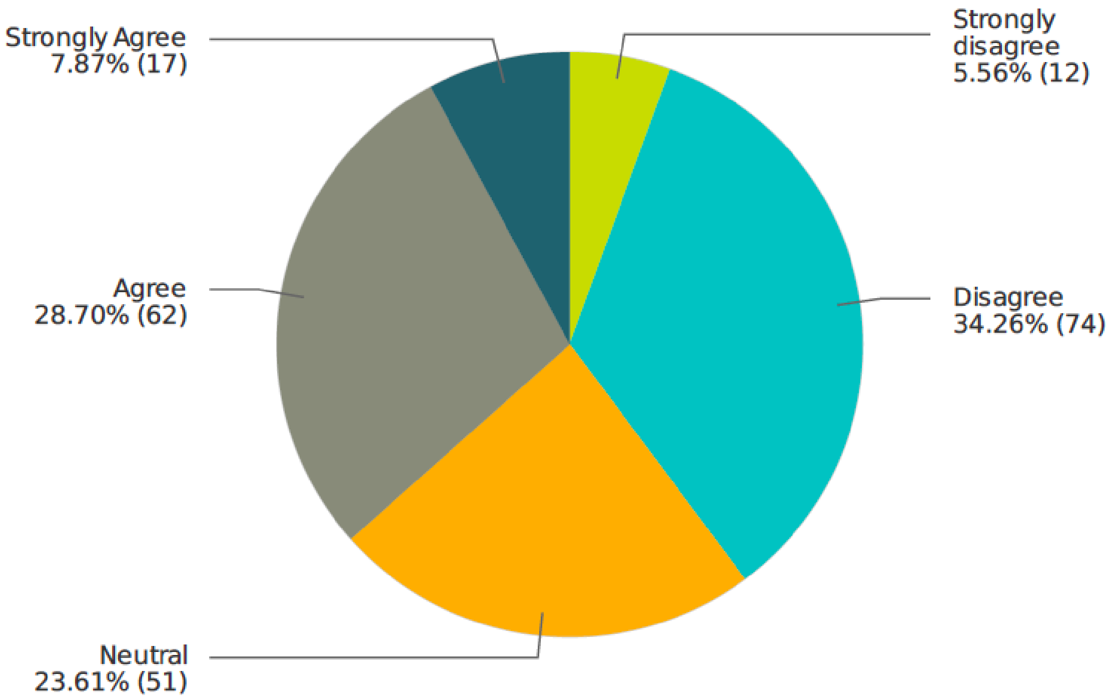
Appendix A – Responses to the Computational Evolution of Digital Art

Participants were asked to give their reaction to the evolved images shown in Table 15. Data was gathered from 216 respondents, all of which were associated with groups or organizations representing relevant expertise in digital artistry and computational evolution. Participants were associated with one or more of the following: IEEE Computer Society, IEEE Society on Social Implications of Technology, Tech Plus LinkedIn Group, teaching faculty at Cork Institute of Technology, College of Arts, Celtic Studies and Social Science at University College Cork, and researchers in Digital Arts and Humanities at various international institutions. A number of the respondents were also practicing artists.

These questions were posed as follows, presenting clear statements which participants responded to as either “Strongly Disagree”, “Disagree”, “Neutral”, “Agree” or “Strongly Agree”:

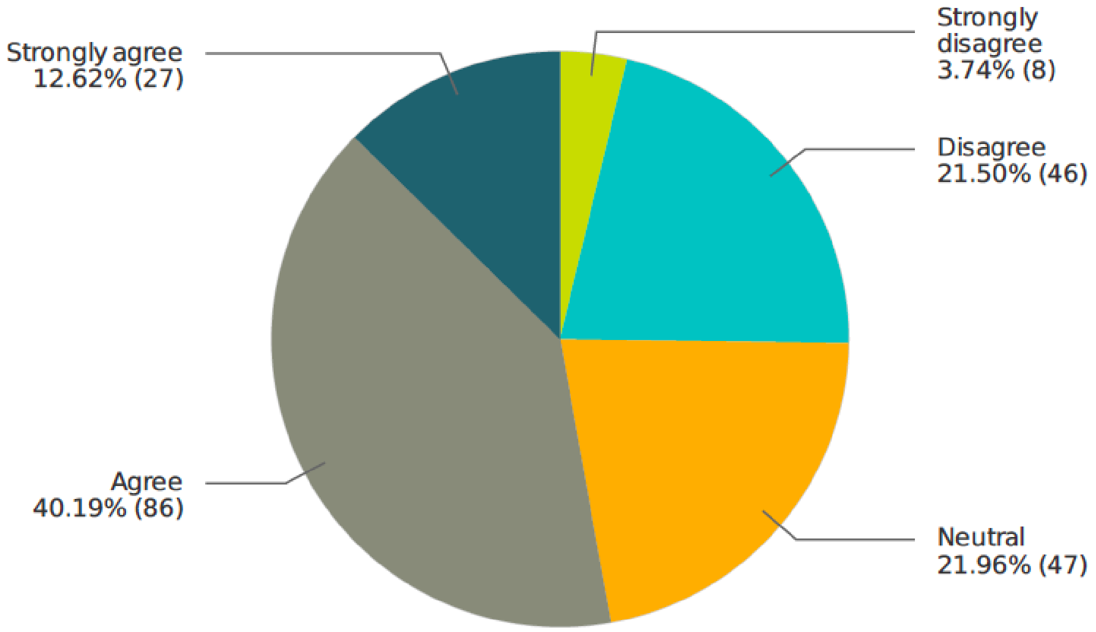
Question 1

The presented images are an accurate representation of landscapes

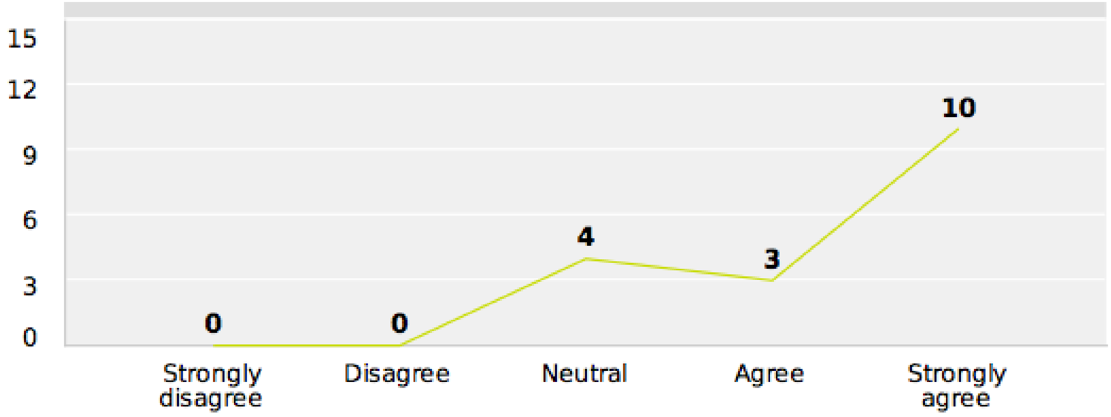


Question 2

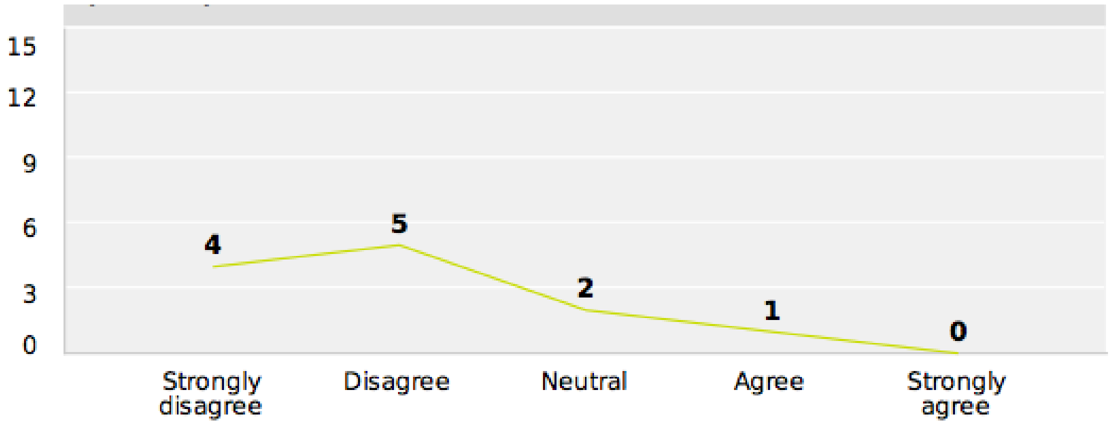
The presented images are aesthetically pleasing



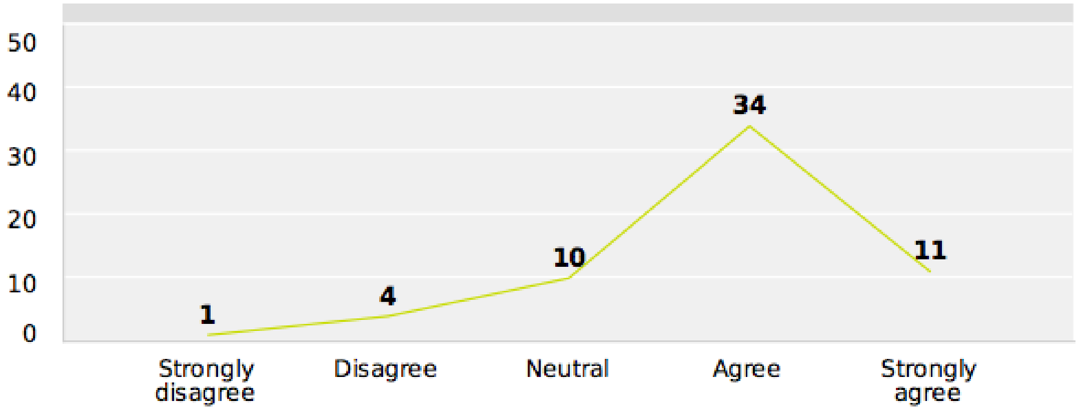
Responses to Question 2 by those who Strongly agreed in Question 1



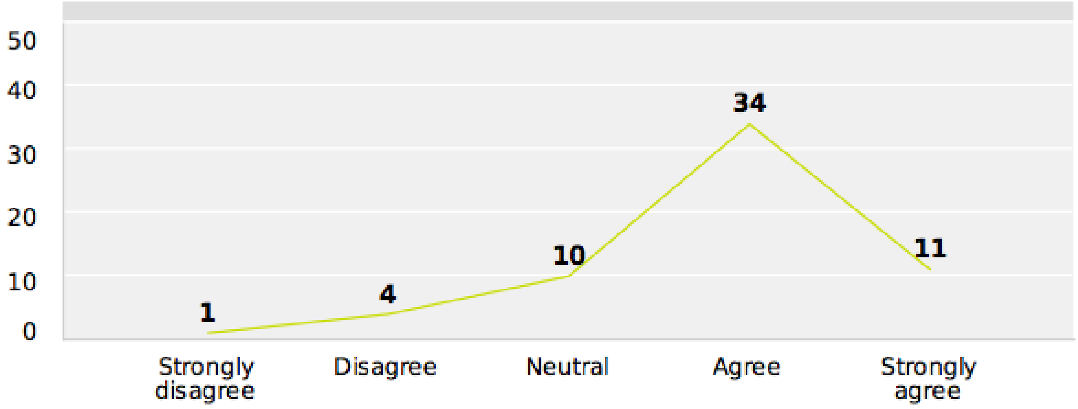
Responses to Question 2 by those who Strongly disagreed in Question 1



Responses to Question 2 by those who agreed in Question 1

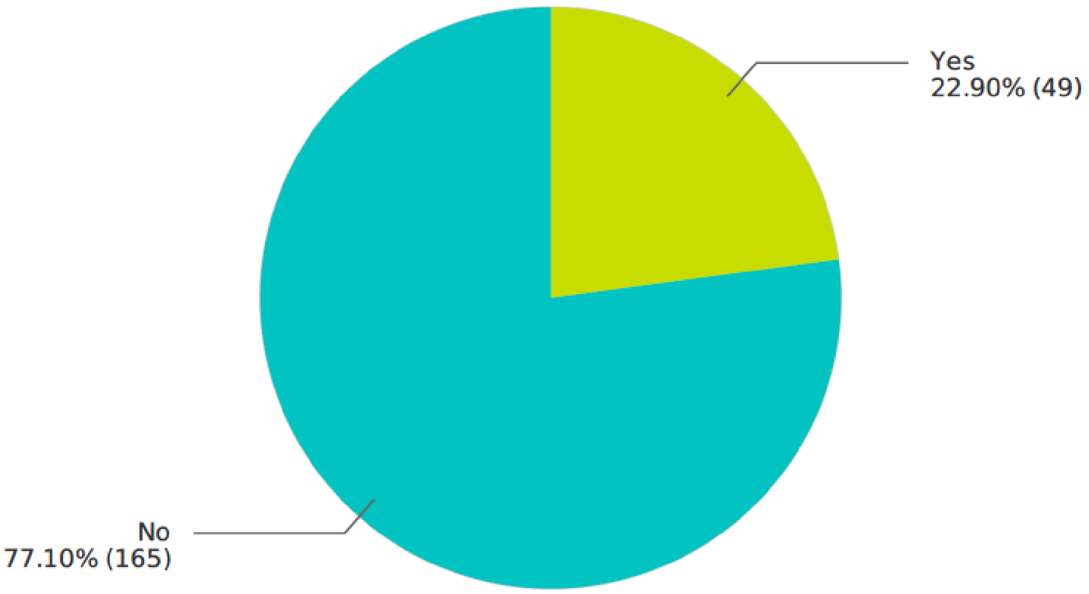


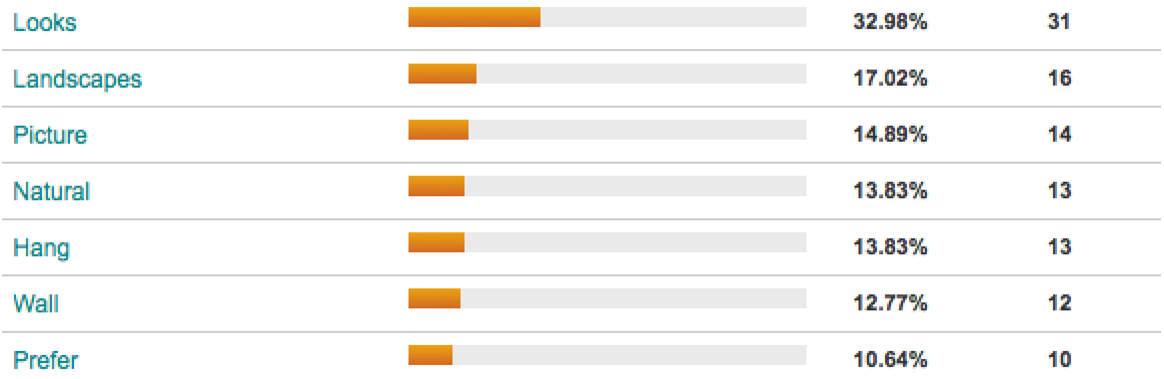
Responses to Question 2 by those who disagreed in Question 1



Question 3

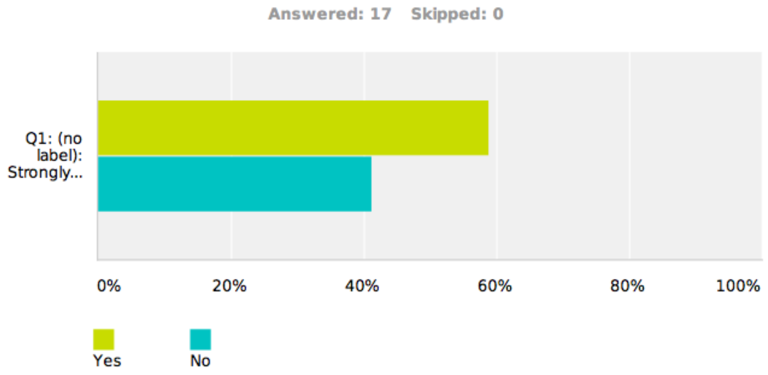
Would you hang images of this style on your wall?

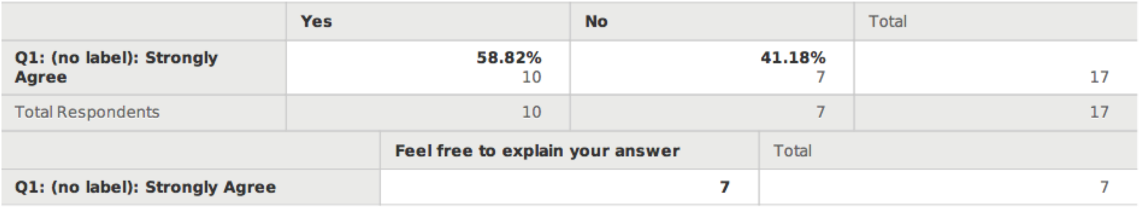




Looks	32.98%	31
Landscapes	17.02%	16
Picture	14.89%	14
Natural	13.83%	13
Hang	13.83%	13
Wall	12.77%	12
Prefer	10.64%	10

Responses to Question 3 by those who Strongly agreed in Question 1

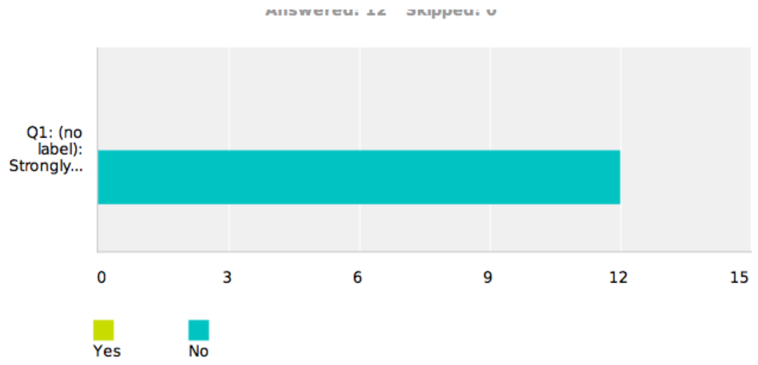


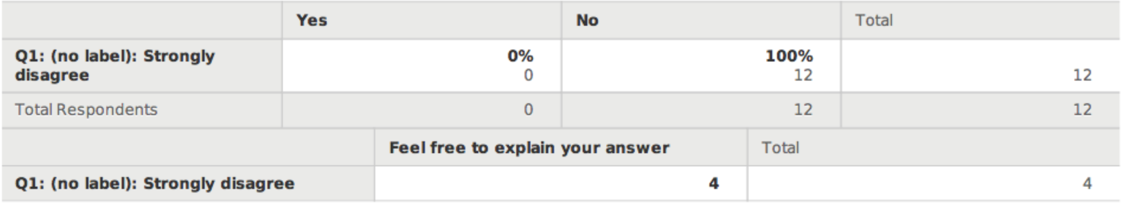


	Yes	No	Total
Q1: (no label): Strongly Agree	**58.82%** 10	**41.18%** 7	17
Total Respondents	10	7	17

	Feel free to explain your answer	Total
Q1: (no label): Strongly Agree	**7**	7

Responses to Question 3 by those who Strongly disagreed in Question 1



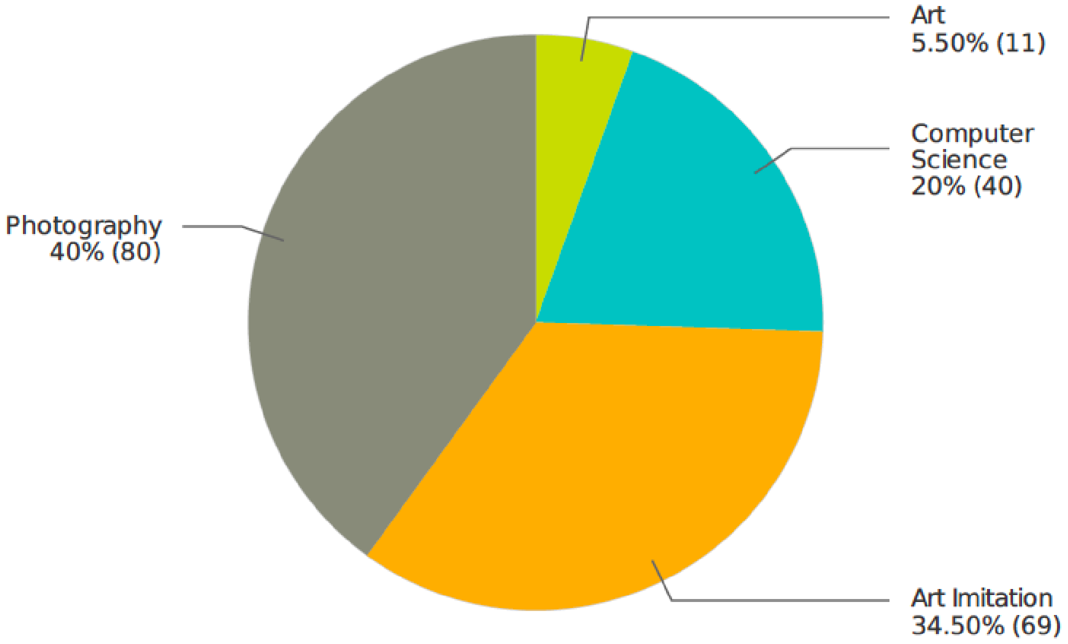


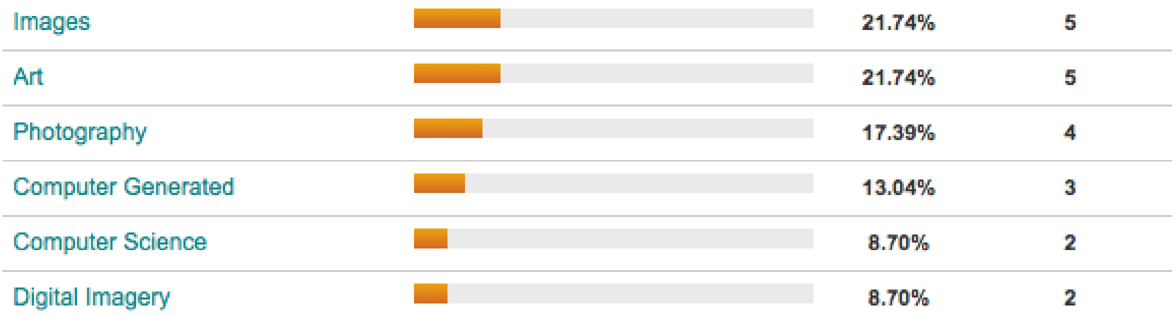
	Yes	No	Total
Q1: (no label): Strongly disagree	**0%** 0	**100%** 12	12
Total Respondents	0	12	12

	Feel free to explain your answer	Total
Q1: (no label): Strongly disagree	**4**	4

Question 4

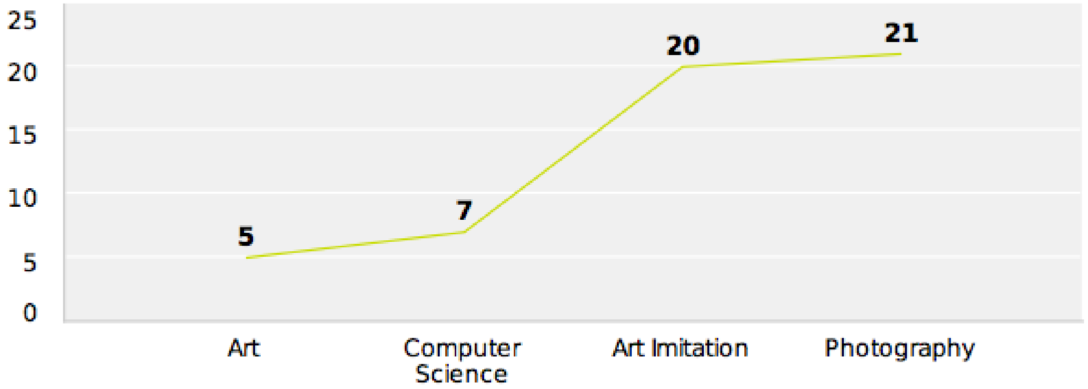
How would you classify these images?



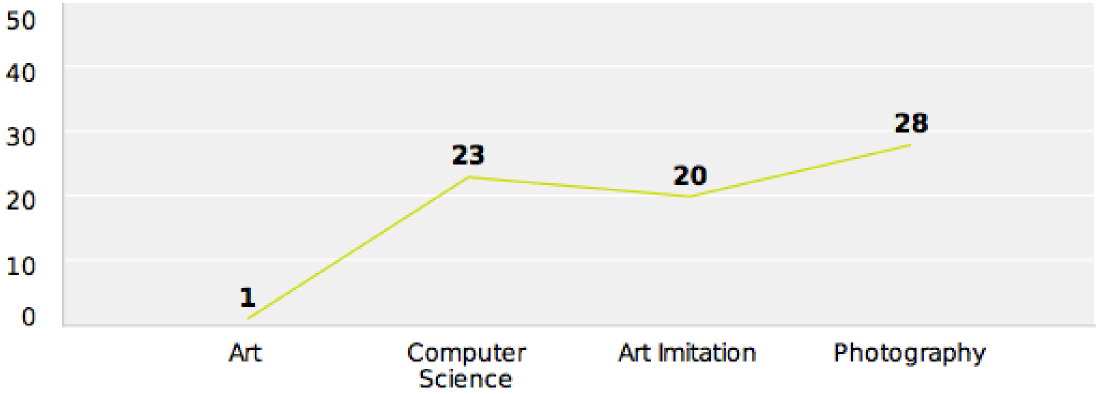


Images	21.74%	5
Art	21.74%	5
Photography	17.39%	4
Computer Generated	13.04%	3
Computer Science	8.70%	2
Digital Imagery	8.70%	2

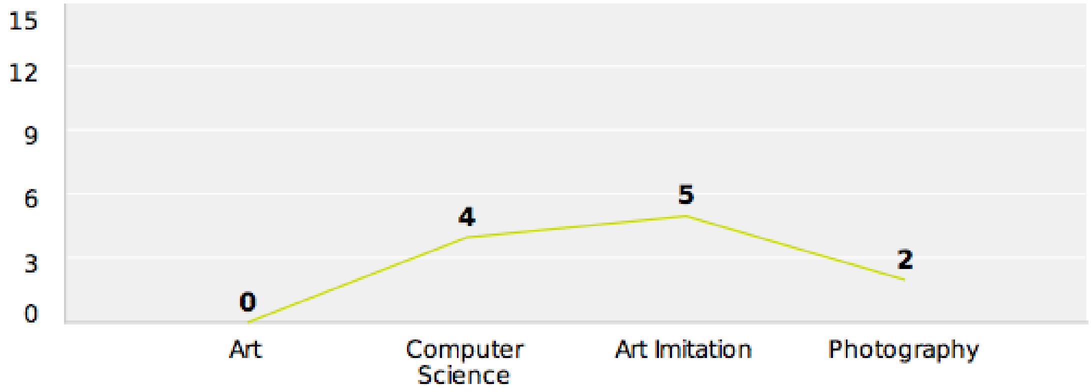
Responses to Question 3 by those who Strongly agreed in Question 1



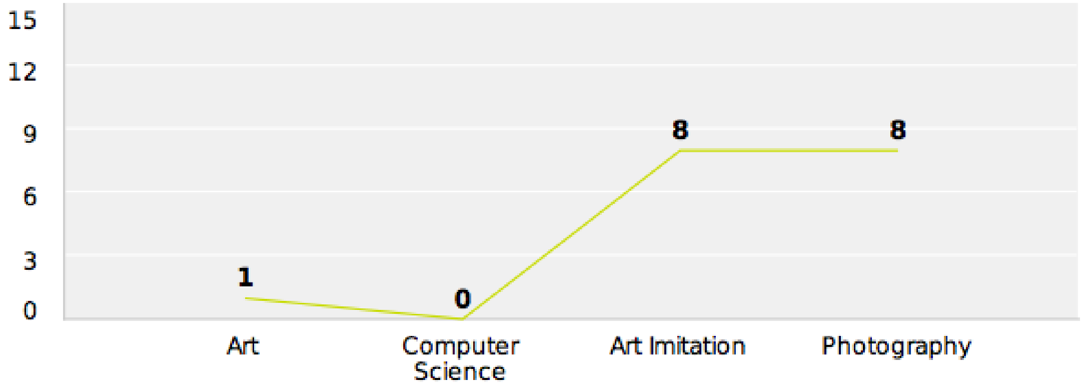
Responses to Question 3 by those who Strongly disagreed in Question 1



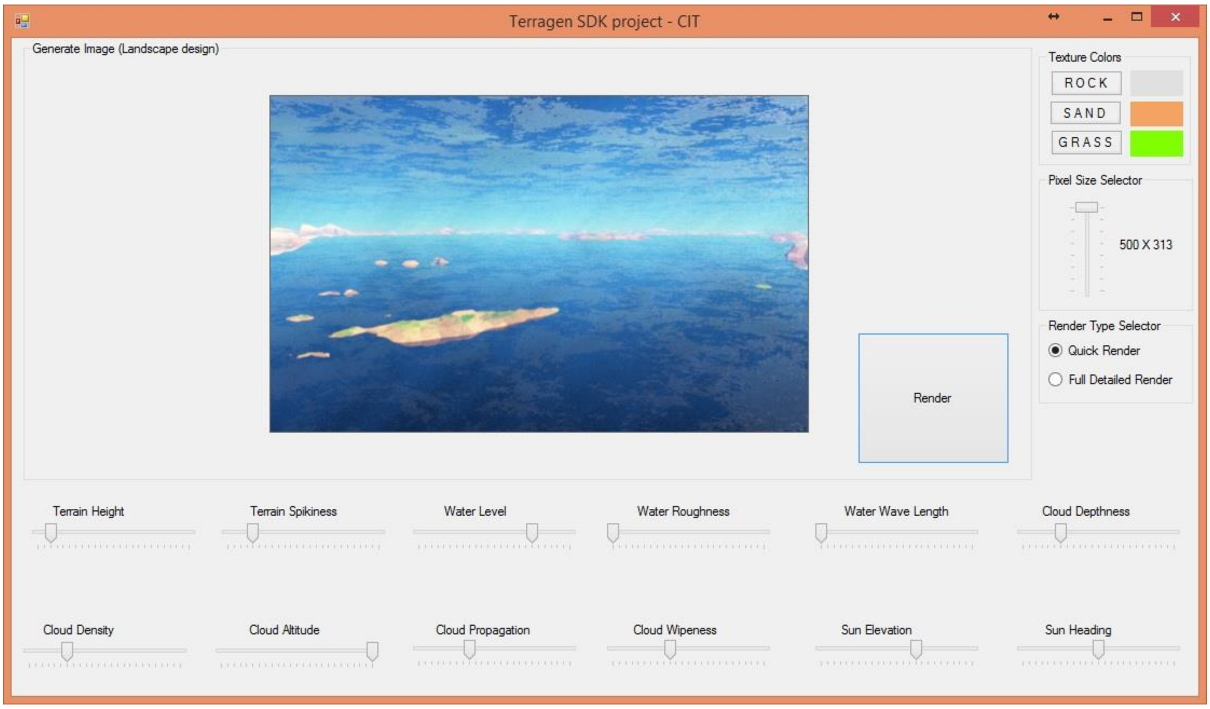
Responses to Question 3 by those who agreed in Question 1



Responses to Question 3 by those who disagreed in Question 1

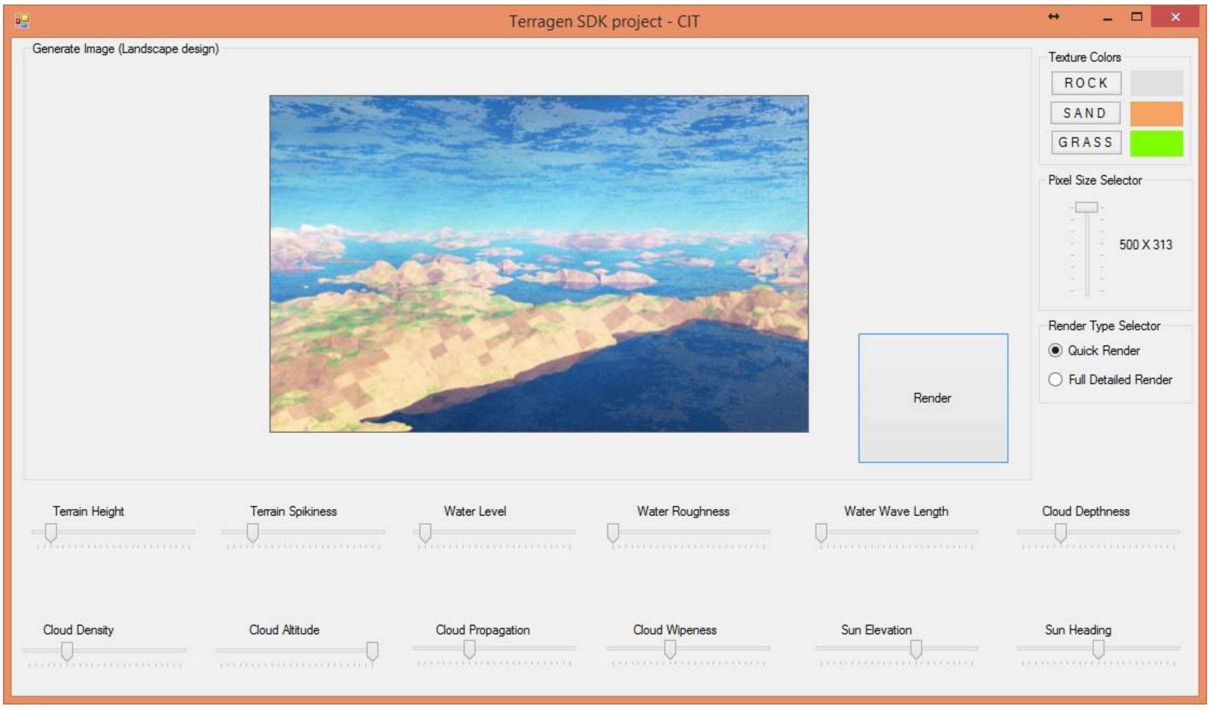


Appendix B – API for Terragen software



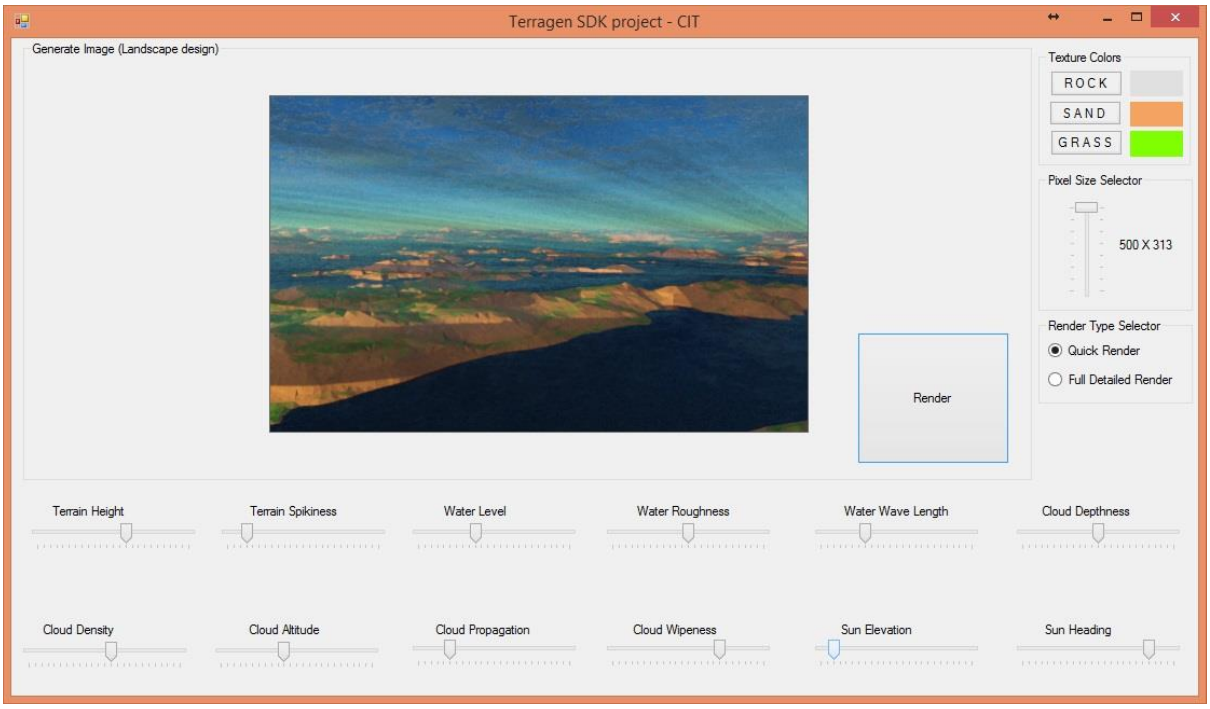
Pixel Size Selector: 500 X 313

Render Type Selector:
● Quick Render
○ Full Detailed Render



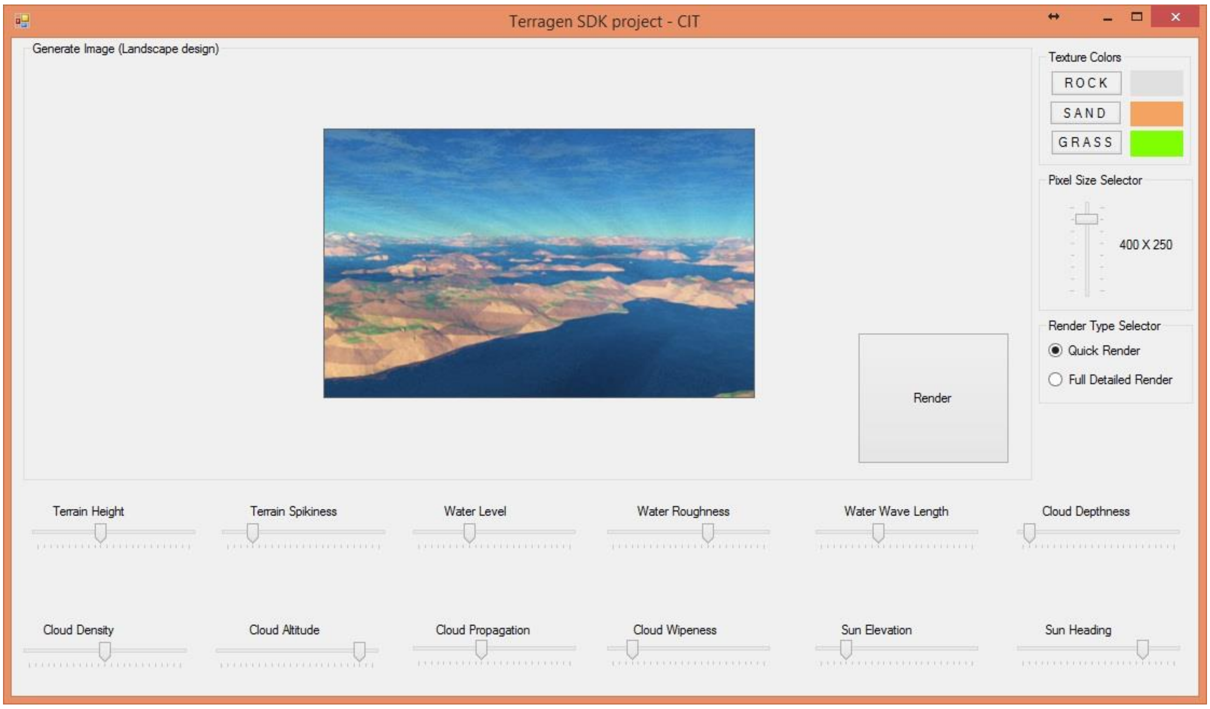
Pixel Size Selector: 500 X 313

Render Type Selector:
● Quick Render
○ Full Detailed Render



Pixel Size Selector: 500 X 313

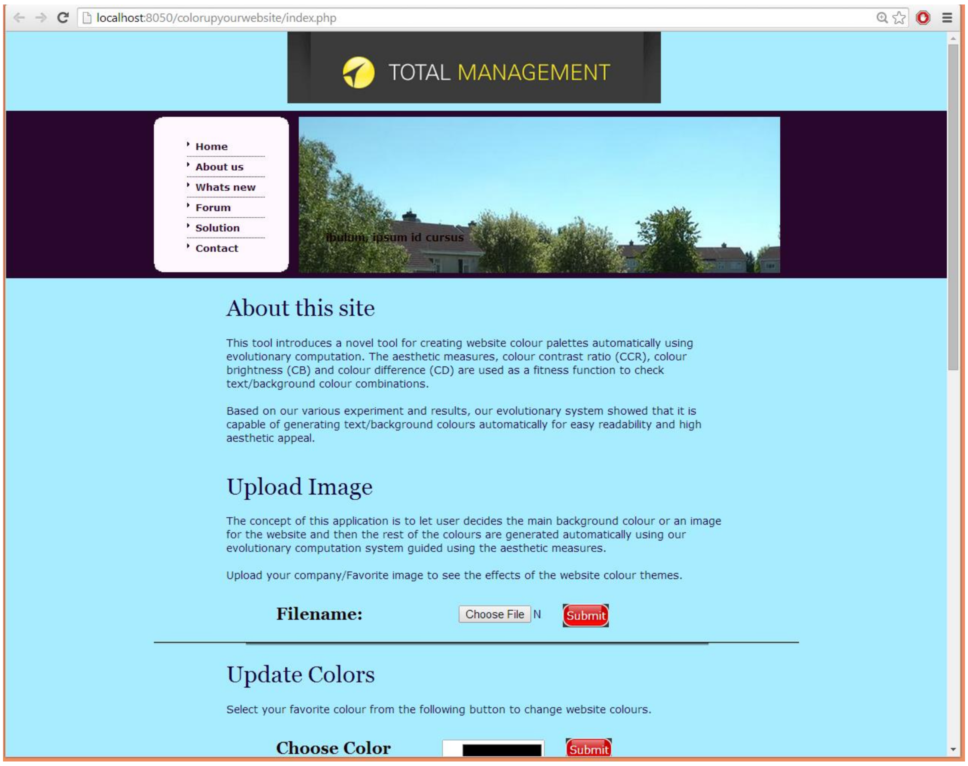
Render Type Selector
● Quick Render
○ Full Detailed Render



Pixel Size Selector: 400 X 250

Render Type Selector
● Quick Render
○ Full Detailed Render

Appendix C – Evolution of website colour schemes based on climate change



About this site

This tool introduces a novel tool for creating website colour palettes automatically using evolutionary computation. The aesthetic measures, colour contrast ratio (CCR), colour brightness (CB) and colour difference (CD) are used as a fitness function to check text/background colour combinations.

Based on our various experiment and results, our evolutionary system showed that it is capable of generating text/background colours automatically for easy readability and high aesthetic appeal.

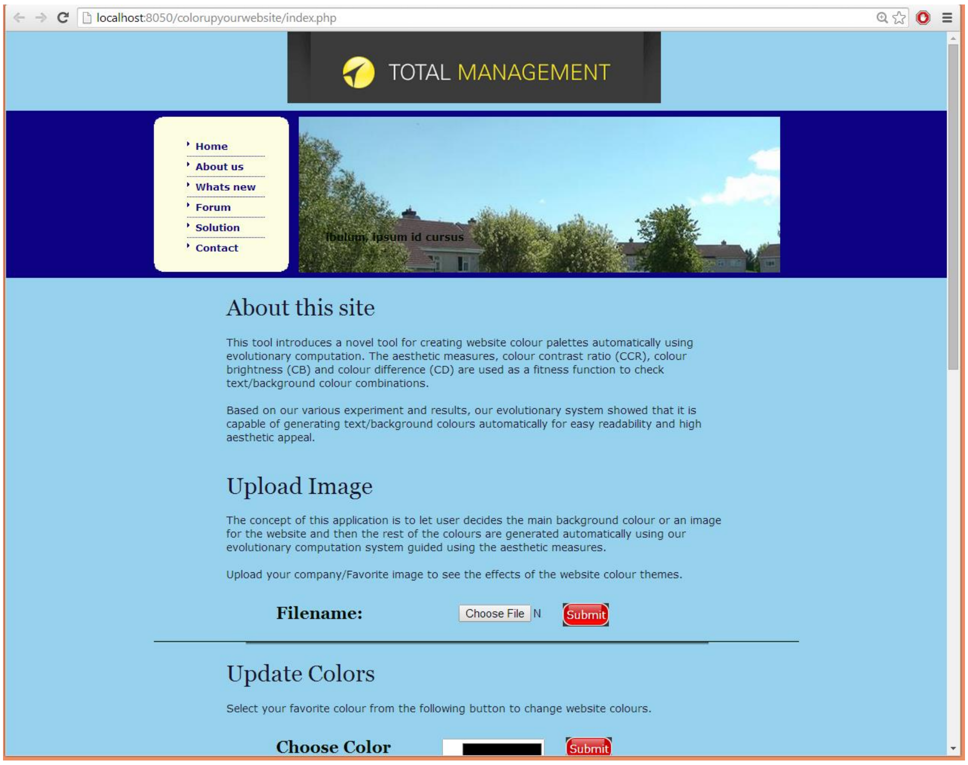
Upload Image

The concept of this application is to let user decides the main background colour or an image for the website and then the rest of the colours are generated automatically using our evolutionary computation system guided using the aesthetic measures.

Upload your company/Favorite image to see the effects of the website colour themes.

Update Colors

Select your favorite colour from the following button to change website colours.



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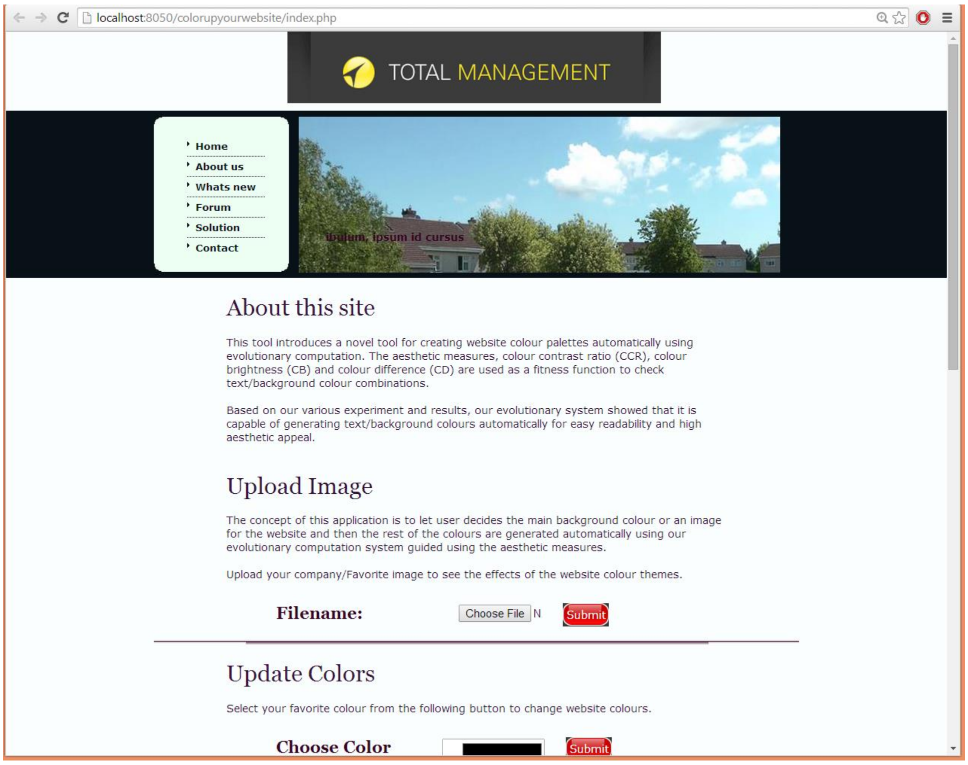
Select your favorite colour from the following button to change website colours.



About this site

This tool introduces a novel tool for creating website colour palettes automatically using evolutionary computation. The aesthetic measures, colour contrast ratio (CCR), colour brightness (CB) and colour difference (CD) are used as a fitness function to check text/background colour combinations.

Based on our various experiment and results, our evolutionary system showed that it is capable of generating text/background colours automatically for easy readability and high aesthetic appeal.

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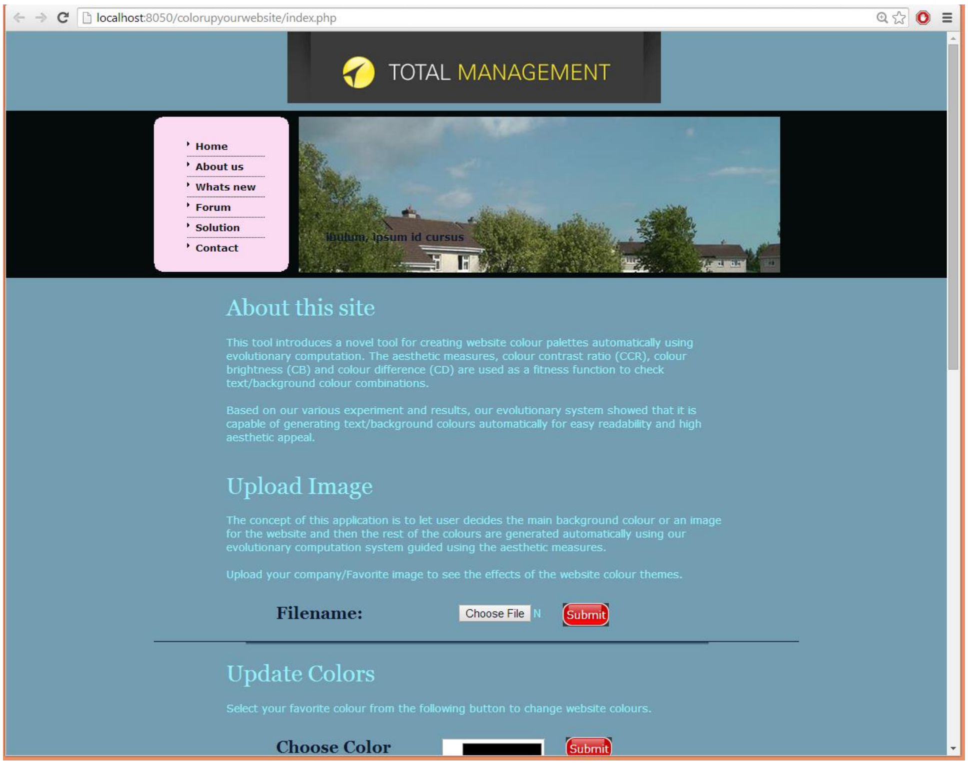

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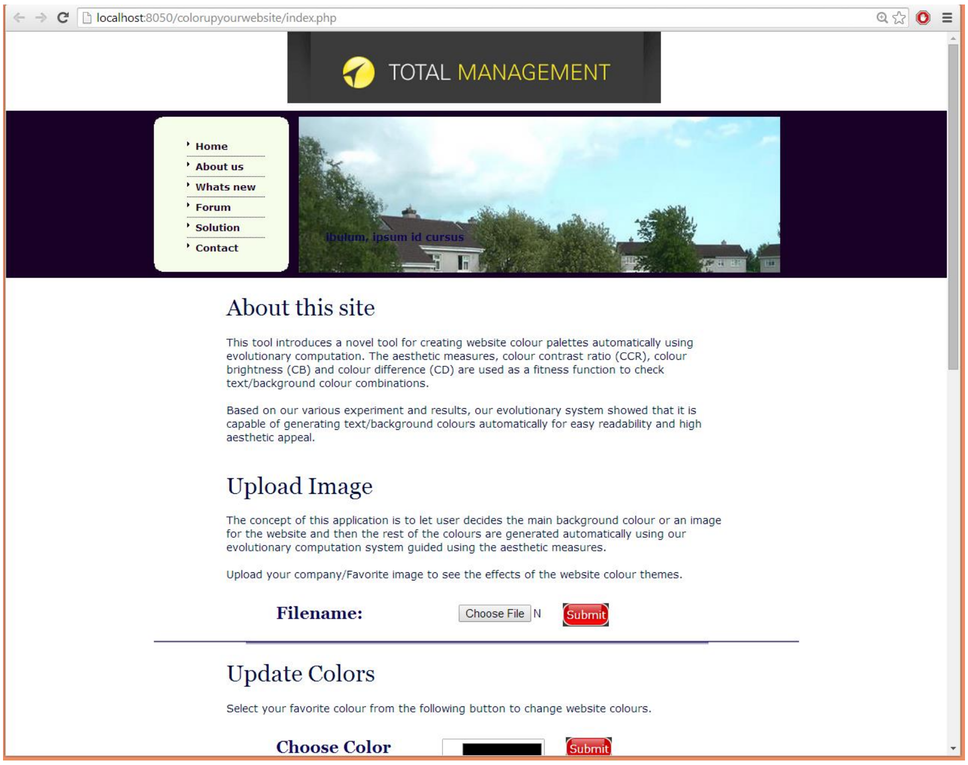

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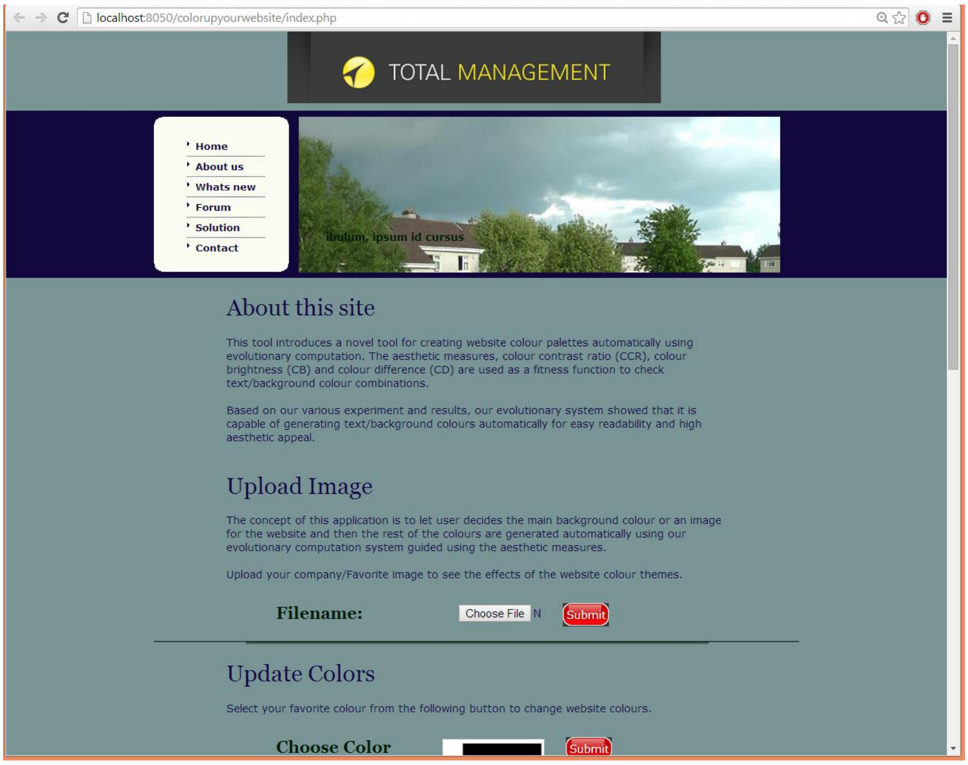

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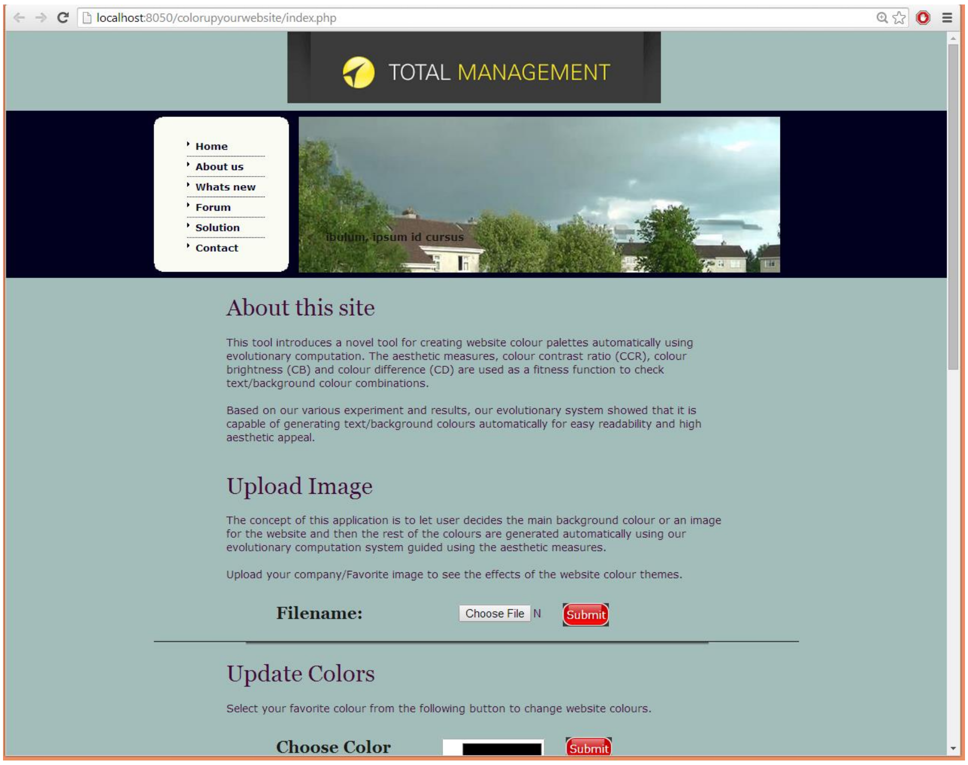

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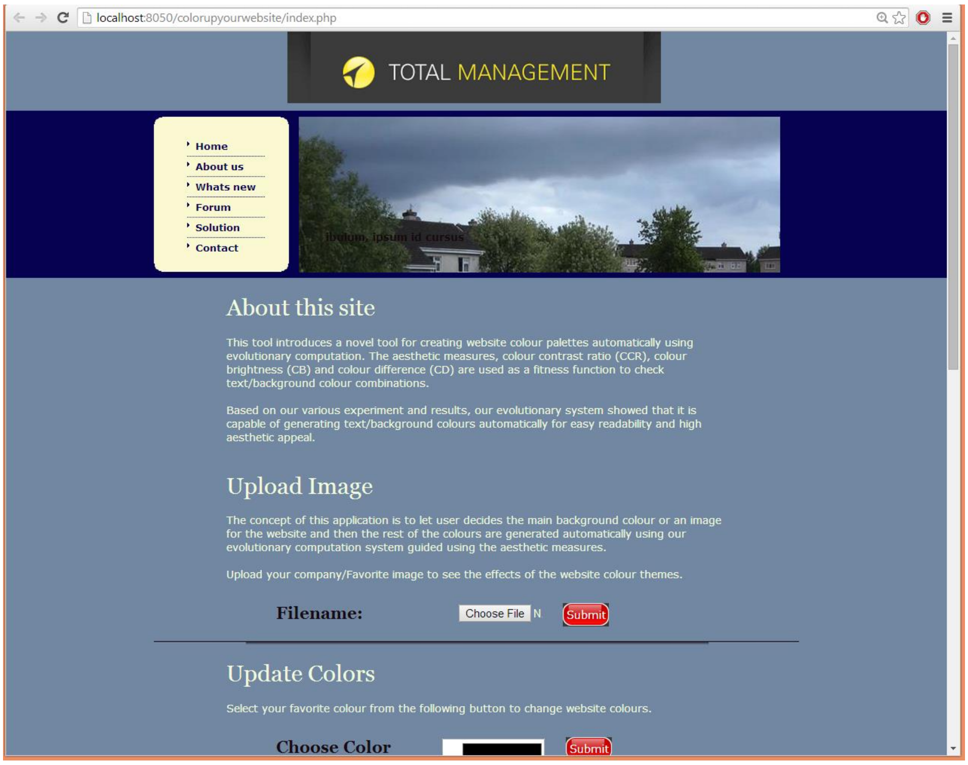

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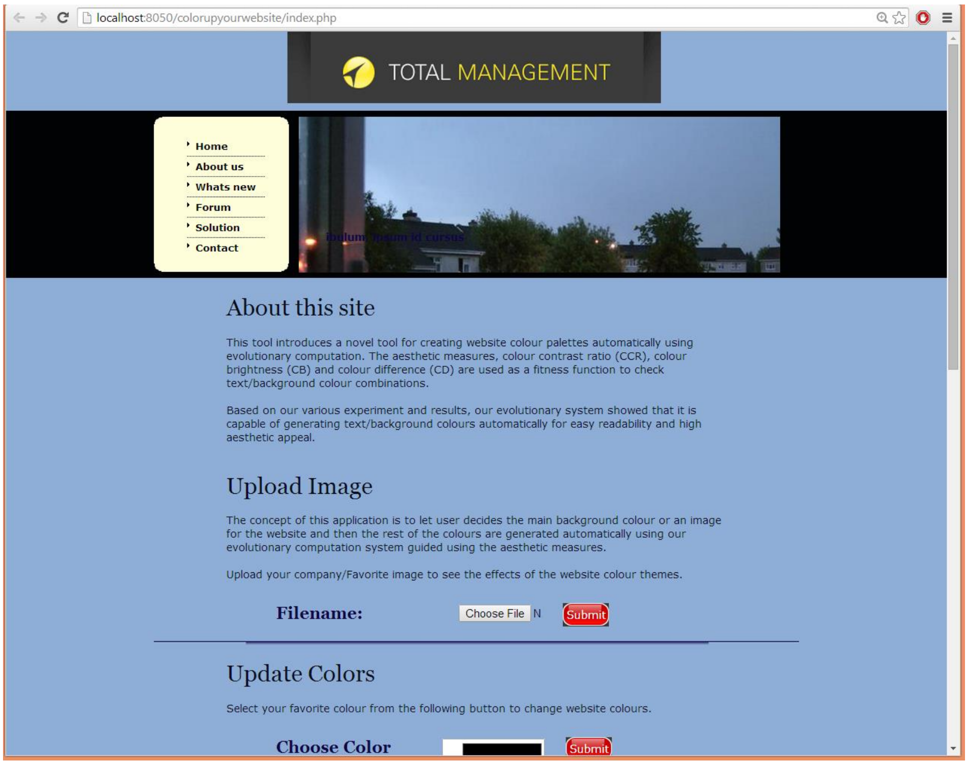

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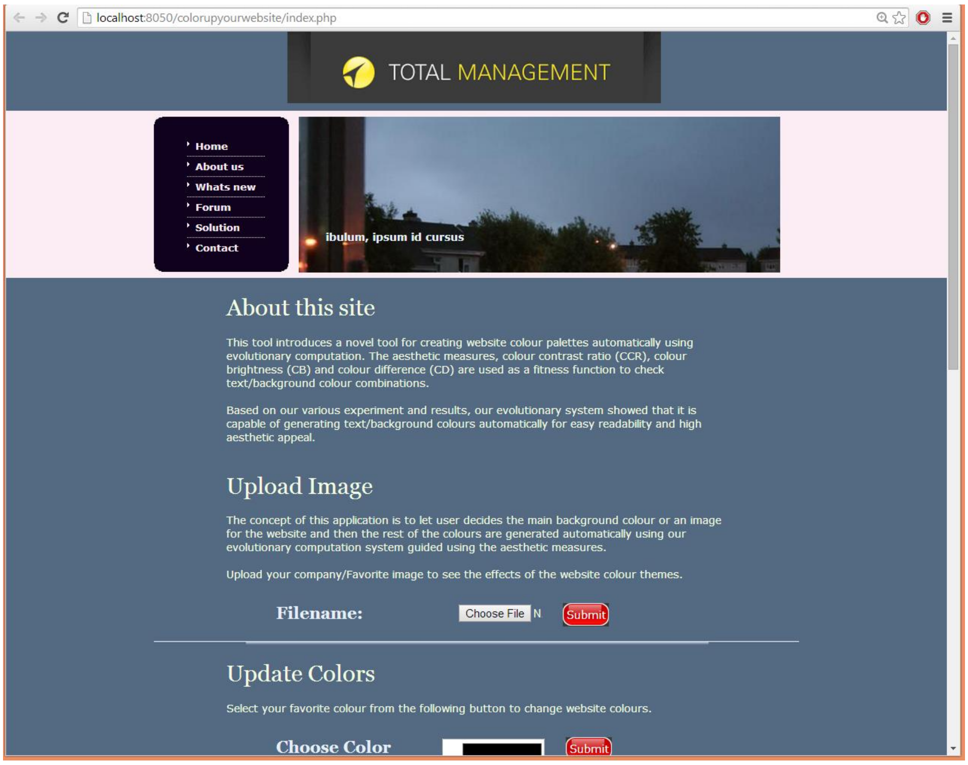

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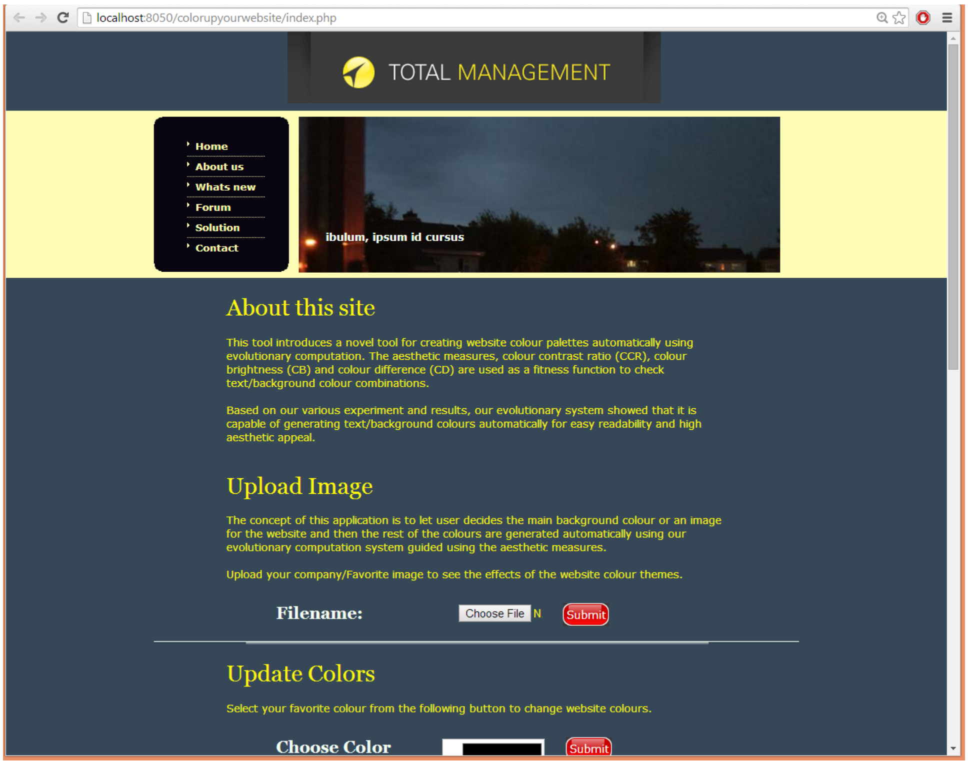

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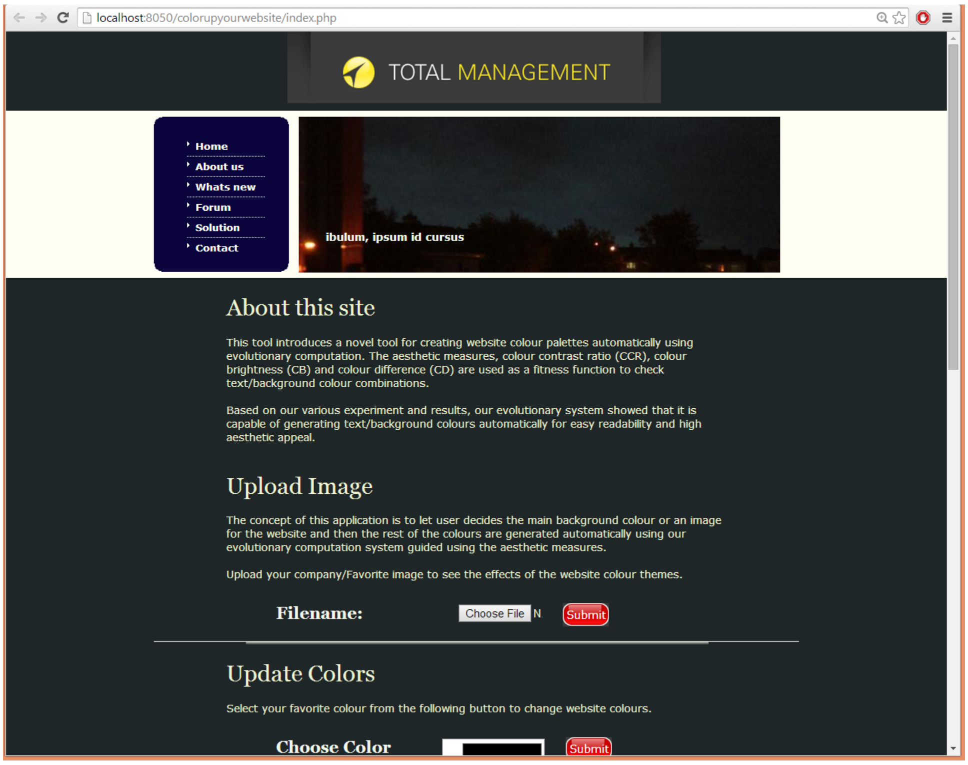

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