The use of computers english language essay

Linguistics, English

Leach [[1]] introduces the idea of traditional, top-down method, where the form is prescribed by the designer and all sustainable and structural criteria are solved at a latter part of the design, and how more contemporary, bottom-up methods, where the processes that produce the form and defined, are now being explored. This research and development into this new kind of design method is utilising computers and taking influence from natural processes to, as claimed by Roudavski [[2]], resolve challenges already solved by nature. This literature review will look at how science and technology are beginning to influence the fields of generative design within the construction industry. It will then focus on the intrinsic techniques that are being used and explore the kind of extrinsic forces that can affect the generation of form. This literature review aims to show the positives and negatives of the generative design systems that are occurring in the industry and conclude with how my research will follow and the influences that it draws from.

2. 1 Science and Technology

2. 1. 1 The Use of Computers

The use of computers as a way of analysing and representing structures has been around since the nineteen sixties, when Eero Saarinen used early structural-analysis software to construct the Trans World Flight Centre Terminal in 1962 [[3]]. Only since the early nineties and then predominantly since the start of the new Millennium have computers have been used as a way of generating designs. With the development of machines with greater and greater amounts of computing power, computers are being used as an effective tool to quickly produce multiple iterations of designs which by hand

could take days. It also can allow modern engineers to understand the work of previous architects. For example Antoni Gaudi spent years developing a method to generate the complex columns via simple geometric rules in the Sagrada Famila in Barcelona [[4]]. However, Gaudi died before the cathedral's completion and did not leave a master-plan of his design. In order to complete the cathedral, Mark Burry, the lead researcher and architect, and his team spent months using physical models and analytical drawing to work out the pattern which according to Burry [[5]] this could have taken minutes using high end parametric software and powerful computers. This capability of computers is being utilised by the construction industry to create a more efficient design process that saves time, money and allows for changes to be implemented quickly. Computers are being used to explore aspects of design which require complex iterative calculations and to research into areas where there is a lack of knowledge. As stated by Kicinger et al. [[6]] the emergence of Information Technology has been the driving force behind the progress in civil engineering. But this works in a larger global circle as a big part of the drive to develop computers has been the inter-disciplinary collaboration between engineers and scientist to model and study natural processes and structures [[7]].

2. 1. 2 Nature and Science

Nature has been able to generate structurally and environmentally efficient forms, for example human bone's efficient concentration of material to resist stress and strain creates an effective strength to weight ratio. A more building-like example is termite mounds that are naturally heated and ventilated and if scaled to human size is equivalent to a 180 storey building.

However if you scale down the human built Sears Tower in Chicago, its structural strength is equivalent to a grass stalk. Eugene Tsui [[8]] uses these examples to show how the building we are producing are inefficient and wasteful and how we should be taking more influence from nature. Although its can be argued that in some areas, such as in vernacular architecture or form-finding design methods, we have managed to achieve greater efficiency. Nature has always directly inspired humans for art and poetry as well as in architecture. Early research by Antoni Gaudi and Frei Otto into natural forms and their exploration into biomimicry shows how nature can help to develop the structural systems that we know today. Gaudi rarely drew his designs but used pliable materials in order to create three-dimensional models which he based on the perfections he saw observed in nature [[9]]. His use of a hanging model to design the structure of the Colonia Guell Church, created a structurally efficient form based on the theory of catenaries that naturally occurs due to gravity. Frei Otto's research into natural form, such as how soap bubbles form the minimal surface area within a given area caused him to become the pioneer of lightweight, strong and economic tensile roof structures. Steadman [[10]] describes how architects such as Frank Lloyd Wright and Le Corbusier began to use more complex natural ideas in their building design. Wright pioneered the idea of organic architecture, where all elements of a building are all related, like an ecological system as well as taking direct influence from their environment. Le Corbusier believed the idea of evolution should be used more by architects. These architects, although they took a step forward by using inspiration from nature, still had a traditional, top –down approach. In

contrast, some engineers have begun to investigate a more bottom-up approach where the designer defines the rules of the processes from which the form generates. John Frazer, pioneer of Evolutionary Architecture, [*Frazer*] explains how the inner logic of nature has influenced this method of form generation. Many of the basic generative design techniques and the concepts of morphological processes have been inspired by this inner logic.

2. 2 Nature's Inner Logic

Evolution is based on Darwin's [[11]] theory of natural selection which states that through each generation of a population, the most successful individuals at surviving pass on their successful attributes to the next generation. Dawkins [[12]] argues that evolution can lead to the complexity of form and that evolution is the reason of our existence. Thompson [[13]] stipulated that there was too much focus on evolution as the predominant way that nature generated its form and that more credit should be given to the properties of a system. He theorised that biological systems could be described mechanically or mathematically rather than being justified through the theory of " survival of the fittest". He the internal structure of the hollow bones of birds to truss designs and his research into the relationship between plants and the Fibonacci Sequence analytical show this. Menges [[14]] states how natural morphogenesis, the developments of form, is influenced by extrinsic forces caused by the environment and intrinsic forces of the mechanics of the system. Johnson's [[15]] exploration of emergence and the similarities between ants, brains, cities and software reveals corroborates these idea that the inner logic of systems can play a larger role in form generation. The similar phenomena of Emergence and Self-

Organisation are often used to describe the same process however there are situations where only one or the other applies. Wolf and Holvoet [[16]] state that emergence occurs when a set of simple rules are applied to individual elements which leads to the complex behaviour of a whole system, while self-organisation describes a dynamic system that adapts to maintains its structure without external influence. A metabolism requires organisms need to consume enough food to stay alive, which according to Manuel De Landa [[17]], endogenises the fitness which then creates emergence. This idea is shown in the agent-based simulation, SugarScape, where agents are given a metabolism which means they have to eat enough sugar in order to survive. As a result, the agents, which would otherwise just move randomly, self-organise themselves around the mounds of sugar. Adaption is when nature's structures adapt themselves due to extrinsic forces. For example, a tree on a slope which has slipped will bend so that its leaves are aligned to get the most sunlight. This creates emergence to occur due to the feedback caused by the leaves not getting enough light.

2. 3 Generative Design

The concept of generative design has been traced back to Aristotle, as outlined by William Mitchell [[18]], with its first use in architecture by Leonardo da Vinci during his study of centrally planned churches. Traditional relationships as claimed by Kolarevic [[19]], like The Golden Ratio and the use of the Cartesian Grid, have always been a way of generating aesthetically pleasing building. These can be argued as top-down, " fixed" methods from which some innovators have been trying to move away from, to new generative design ideas.

2. 3. 1 Generative Design Fields and Digital Morphogenesis

Generative Design Fields is the broad name for the creation and manipulation of structures while Digital Morphogenesis is the specific architectural term for the use of computers to do this. There are many different fields which researchers are beginning to explore, some of which are briefly summarised from works by Nicholas Negropontes [[20]] and Branko Kolarevic [[21]]. Soft Architecture which postulates the idea of an intelligent and responsive physical environment which responds to external and user requirements. Evolutionary Architecture is where the processes of the system are defined to produce the form and then genetic algorithms are predominantly used to evolve designs. Topological Architecture uses Non-Uniform Rational B-Splines which are modified via control points, weights and knots to generate continuous curves and surfaces. Isomorphic Architecture is a space which contains parametric objects with fields of influence of different intensities. Surfaces are then created by connecting all points with equal strength, which can be modified by changing the intensities of the objects. Animate Architecture is where forces and interaction rules are applied to objects, with defined physical properties, which causes movement, animation and evolution of form. Parametric Architecture is where the parameters of the object or the external properties are defined and can be modified. However Menges [*computational morphogenesis*] argues that digital morphogenesis is predominantly focused on aesthetics and does not utilise the capacity of computational morphogenesis to develop the performance capacity of the form. This

highlights the importance of structural reality within the generative design field.

2. 3. 2 Generative Performative Design

Generative Performative Design is a form of Generative Design but one that uses performance criteria [[22]] as a form of creativity rather than aesthetics. The main drawback is that these systems are generally only able to optimise one or possibly two performance criteria. This brief overview is to highlight some of the methods that are currently being used in the industry.

2. 3. 2. 1 Generative Design System

The Generative Design System [GDS] is generative design software created by Luis Caldas in 2001 that optimises environmental factors. It uses optimisation algorithms and genetic algorithms to optimise the lighting and thermal performances of building envelopes [[23]] creating innovative, energy efficient facades.

2. 3. 2. 2 Digital Tectonics

Digital Tectonics is a sub set of Generative Performative Design which specifically optimises material, structure and fabrication. As shown in the successful models and structures at the Fabricate Conference and the book published alongside it [[24]] shows how material knowledge has been exploited to generate sustainable designs.

2. 3. 2. 2. 1 eifFORM

eifFORM is a structural optimisation generative design software created by Kristina Shea in 2000. It uses structural grammars, structural analysis and

optimisation in the form of simulated annealing to optimise structural behaviour, space and cost [[25]]. Shea admits that the software still needs some internal hacking and programming for individual projects by designers [[26]]. Chase [[27]] states how there are very few successful generative design tools due to the complexity of most structural problems and inappropriate interfaces.

2. 3. 2 Generative Design Techniques

Gu and Singh suggest that most generative design systems are based on one, or sometimes two, of five basic techniques; Shape Grammars, L-Systems, Cellular Automata, Genetic Algorithms [[28]]. Each has their own positives and negatives and some are more suited to certain aspects of design than others which will be discussed below.

2. 3. 2. 1 Shape Grammars

Shape Grammars were created by George Stiny and James Gips in 1971 and are now being used as a way of generating or analysing designs. It consists of simple transformation rules which are applied to geometries. Kristina Shea[*Dig Tect*] states how the sets of rules create a specific style which means all the forms generated by the same set of rules are of a similar design language or mimic that of another designer's. This is useful if researching another's work but could be a hindrance if wanting to produce innovative forms.

2. 3. 2. 2 Lindenmayer-Systems (L-Systems)

L-Systems were created by Aristid Lindenmayer in 1968 to model the growth of plants but now have been used to for city design. Designs are generated

by a set of rules that are iteratively applied to write and rewrite an initial string. L-Systems are not dissimilar to Shape Grammars and are both a simple way of creating an emergent pattern. It can be argued that these are still quite a prescribed technique and it can be argued that they are not an effective tool to produce innovative designs.

2. 3. 2. 3 Cellular Automata

Cellular Automata was first described by John Von Neumann in 1951 and has been used generate building and urban designs. It is made up of a grid of cells, whose state is defined by its neighbouring cells. The most famous Cellular Automata is John Conway Horton's Game of Life, which is made up of a grid of cells which are either dead or alive. The cell's state is defined by a set of rules; if a cell has less than two neighbours, it dies of loneliness or becomes alive if it has three neighbours. The Cellular Automata has more recently been pioneered by Wolfram [[29]], who claims his disbelief in evolution as the main cause complex form generation and promotes the idea and relevance of simple systems creating complexity. The main problem is that the patterns are limited to the size of the grid which means a restricted exploration of the design space and therefore design options.

2. 3. 2. 4 Swarm Intelligence

Swarm Intelligence was initially used by Jean Deneubourg in 1977 as a way of describing a property of a system where the interaction of an individual with other individuals and its environment leads to a global effect, for example a flock of birds. This is another example of a simple system but using autonomous agents mean that, unlike Cellular Automata, the system is

not constrained to a grid. Both Cellular Automata and Swarm Intelligence are more bottom-up techniques as the rules of the processes that create the patterns are defined.

2. 3. 2. 5 Genetic Algorithm

Genetic Algorithms were introduced by John Holland in 1975 and is predominantly being used as way of optimising many design aspects. Optimisation occurs by evaluating a population of results by a fitness function and then mutating or recombining the highest ranking results. This technique is based on the idea of Darwin's natural selection. The most examined optimisation problem is that of The Travelling Salesman, where an agent needs to travel to a number of cities by the smallest distance possible. The problem with many optimisation systems is that they produce multiple optimal solutions but don't necessarily find the optimum. Danny Hillis [*Emergence*] solved this by adding a predator so if his number sorting system got stuck at a false peak in the fitness landscape it would be forced to keep searching or be eaten. As claimed by Peter Von Buelow [[30]], another issue with optimisation is fixation, where the designer fixates on a solution before all the options are completely explored and therefore not finding the optimum solution. From the argument above, this potentially should not be the main focus in form generation but work alongside a more structuralism approach as advocated by Thompson [*ON GROWTH …]. Gu and Singh[**] comment on the limitations of these techniques and promote the idea of an integrated system which incorporates most, if not all, of these techniques to utilise their positives, which would mean a better exploration the design space. Others such as Saridakis and Dentsoras [[31]], suggest the

application of soft computing techniques like fuzzy logic, neural networks and metaheuristic methods as other suitable techniques alongside these stated above. These will not be explored within this review but it is worth noting there are many more generative design techniques other than just those named.

2. 4 Extrinsic Forces

As claimed by Przemyslaw Jaworski [[32]], the development of the shape and form or all living things are linked to an external force.

2. 4. 1 Fields

A field in terms of physics, is defined by Gribbin [[33]] as a physical quantity that has a value for every point in space and time. The most common fields are Gravitational which represents the influence of masses upon each other, and Electromagnetic which represents the influence of moving charged particles. By using fields you begin to step into the realm of form-finding, which can bring a sense of reality back to the 3D design space . El-Ali [[34]] states that free-form designs have been generated without material and structural properties while form-finding designs are reliant on physical fields, material properties and boundary constraints.

2. 4. 2 Attractors

According to Robert Pryor and Jim Bright [[35]] an attractor is a state that a system evolves towards and adapts to maintain via self-organisation, even when subject to change via intrinsic or extrinsic forces. The four main types of attractors are Fixed Point, Limit Cycle, Limit Tori and Strange Attractor. Both the concepts of fields and attractors, adds a new dimension into the

exploration space which is how a form grows with time. Within the industry, people have more commonly opted for optimisation techniques to generate form, however the techniques named above have more been used in the art world to develop sculptures and pieces of art.

2. 5 Art and Sculptures

Sculptors, such as Antony Gormley, have begun to team up with design engineers, like Tristian Simmonds, to use computational design to generate sculptures such as Quantum Cloud. To create Quantum Cloud (Fig. 1), Antony Gormley used a random walk algorithm on tetrahedral units to generate his structure [[36]]. It can be argued that this is still quite a contrived method of generating a structure and if you compare it to the artwork of Casey Reas, who uses the idea of emergence to generate his Process series, you can see the kind of complexities that this kind of method can produce (Fig. 2). Reas [*Video*] states Process 4 (Fig. 2) is generated by varying sized elements made up of a form (a circle) and four simple behavioural interaction rules. Then by drawing a line between the centre of each element and relating the colour of each line to its length. Reas used his own software Processing to achieve his artwork which shows how this very visual software can be used to achieve interesting patterns. Process 4http://www. lusas. com/case/civil/images/quantum_cloud_front_775. jpgFig. 1 Quantum Cloud – Antony Gormley [*LUCAS*] Fig. 2 Process 4- Casey Reas [[37]]

2. 6 Conclusion

This field is very broad with many different researchers taking different approaches in order to generate designs. Each method has succeeded in some ways and failed in others. The gap in the field is a method of combining more than one techniques or a way of solving more than one problem. The predominant focus of generative design in the industry is on optimisation but it can be argued that we need to take a step back to the way the form is generated originally by using intrinsic and extrinsic forces. My research will aim to create a way of generating forms that can be converted to reality by taking inspiration from nature and the current methods of form generation.