A Brief History and Tentative Taxonomy of Digital Landscape Architecture

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Abstract: "Digital landscape architecture" may either mean "digital approaches to the design of analog landscapes" or "the design of digital landscapes". These two distinct meanings challenge some conventional assumptions about landscapes and landscape elements; and highlight emergent (increasingly digital) approaches to the design, construction, and enjoyment of landscapes. For descriptive and analytical purposes, I propose a distinction between analog / pre-digital ('Olmstedian') landscapes and ('post-Olmstedian') digital landscapes, where the digital component may be only in representation (the most common form to date); in algorithmic conception, or in robotic construction (increasingly common); or in embedded digital components and cyber-physical landscape features (still rare). In the not-so-distant future I predict we will likely see hybrid organic/digital ('bionic') landscapes.

Keywords: Digital landscape architecture, history, representation, cybernetics, technology, design

1 Introduction

The term "digital landscape architecture" is open to two different interpretations: "digital approaches to landscape architecture" or "the architecture (structure, function, and meanings) of digital landscapes". These two distinct but intertwined meanings lead to subtle differences in attention, emphasis, and interpretation of the last half century or so of developments in this area, and of the contents of the last two decades of DLA Conference presentations. One part of this history is a purely instrumental story of inventions, technologies, and capabilities; the other part is an interconnected web of ideas, adoptions, applications, and social and human needs and intentions. Both deserve attention.

This brief reflective survey of the recent history of digital landscape architecture (effectively starting with the invention of the transistor in 1948) follows two threads – chronological and thematic – through these above two possible meanings. The first (chronological) thread covers five critical eras with somewhat arbitrary but intentionally chosen time-frames: the 'Pre-Computer' era, lasting from antiquity to roughly 1950; the 'Early Computation' decades, 1950-1977; the 'Microcomputer era', 1978-1990; the 'Internet & Fabrication era', 1991-2006; and the 'Ubiquitous Computing' era of iPhones, IoT, etc. that we are currently in, 2007 – present. At the end, a brief peek into the future is called prospectively the era of 'Enormous Data and Cyber-Physical Systems' (Table 1). The second thread (thematic) follows ERVIN's (2016) six 'Cybernetic Design' stages of "occupation, perception, analysis, design, communication, and construction". Within each of the five eras, this history recounts both technological developments and dependencies, and also considers impacts and implications on the aforementioned design stages. This review leads to a tentative taxonomy to describe seven distinct kinds of digital landscapes, from basic digitally-enabled representations (using computer graphics); to virtual (VR) and augmented (AR) landscapes; to algorithmic landscapes conceived and constructed with computational aids; to cyber-physical landscapes incorporating physical digital landscape features; and finally, to future artificial bionic landscapes (Table 2).

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Table 1: Five Eras & Three Epochs of Digital Landscape Architecture

Era:	Pre – 1950	1950-1977	1978-1990	1991-2006	2007 – present	Future
Technologies:	Pre-digital	Early computation	Micro-computers	Internet & Fabrication	Ubiquitous computing	Enormous Data, Cyber-Physical Systems
Landscape Epoch:	'Olmstedian'	'Post-Olmstedian': digitally-enabled representation & construction; digital landscape features				Bionic Landscapes

1.1 Pre-Computation: Pre – 1950

Since antiquity, built landscapes have been designed and constructed from the raw material of the natural landscape. These familiar landscapes were both ornamental and functional; designed and used for contemplation, recreation, and scenic value. These pre-digital, centuries-old traditional/conventional landscapes and practices – I will call them 'Olmstedian' – still dominate the globe, and the vast majority of the human landscape experiences. The term 'Olmstedian' is not intended to be specific to that iconic work, or time, or entirely Western/European in its application, but only meant to evoke the elements and approaches of classical landscapes such as New York's Central Park, Le Nôtre's Versailles or indeed, the gardens at Souzhou, China: topography and geology, vegetation, water, and structures, with an emphasis on scenic, recreational, contemplative, and ecological processes and activities, with strong agricultural and horticultural influences. These attributes are coupled with design, conception, and communication technologies based on hand-drawing, graphite, india ink, pens and brushes, tracing paper, vellum, et al.

Earliest concepts of computation can be traced back to Babbage in the 1800s, but it was really from the war years of the 1940s that modern computing emerged. At the very end of this period, Nobert Weiner, one of a group of MIT scientists who laid the seeds for the coming revolution in cognitive science, computer science and Artificial Intelligence (AI), coined the term 'Cybernetics' in 1948 – coincident with the invention of the transistor. These two developments effectively heralded the Computer Era, or Information Age.

1.2 'Early Computation': 1950-1977

With the post-war development of war-time technologies – mainframe computers, the first satellites, telecommunications, and the first stirrings of AI – through to the mid-seventies when these technologies were all in vigorous bloom, came the very first digital landscapes – but only in the form of representations, either as data structures, or as graphics.

Starting with very early developments in computation in the pre-war years, and intensive efforts during the war years, the 1950s saw a veritable whirlwind of developments, including the UNIVAC (first stored-program computer), IBM's first commercial computer, and the development of digital memory, magnetic storage, electronic printers and CRT displays, and all the machinery that came along with these developments. All of this was far too complex and expensive to have any impact on landscape architects' daily life or work, except in their creeping influences on banking, record-keeping, and such mega-science projects as weather forecasting and transportation analysis. The first commercial, digital and programmable

robot (the 'Unimate') was built in 1954; but all the early applications of robotics were in factories, and nobody thought about digital robots in the landscape at first (perhaps not until the next decade, with MARX's (1964) *The Machine in the Garden*).

In the early 1960s the first CAD software appeared: Sutherland's seminal 'Sketchpad' at MIT. By the mid-1960s, computers were powerful, affordable, and ubiquitous enough that universities and large corporations had them; and in that context the formation of the Harvard Laboratory for Computer Graphics and Spatial Analysis (LCGSA), and its early computer mapping software, was a notable turning point for digital landscape architecture. SIMON (1969), in his influential *Sciences of the Artificial*, addressed computers in design, and highlighted the potential for optimization as a generative approach to form; GERO's (1970) *Computers in architectural science* already began to stake out the territory for the following 50 years of research and development; and MOORE's (1970) *Emerging Methods in Environment and Planning* articulated a wide range of ideas about applications of and the impact of computational design, from a conference at MIT (mostly from architects and planners; few if any landscape architects were represented.) In the 1970s the LCGA's software evolved into the very earliest form of geospatial processing that became modern GIS; and GIS developed a growing community of users, including some landscape architects, increasingly using software for description and analysis, though typically not for prescription (design).

With respect to the 'cybernetic design' stages, these developments most strongly impacted perception, analysis, and communication; occupation, design and construction were relatively un-affected. These were all basically new digital approaches to representing and analyzing conventional landscape architecture with purely analog ('Olmstedian') elements.

1.3 'Microcomputers': 1978-1990

In this era, sparked by the Apple I, floppy disks, and then the IBM PC, the microcomputer revolution transformed the digital landscape. The first 'killer apps' were word-processing and number-crunching (spreadsheets); followed shortly by image processing (Photoshop) and CAD (AutoCAD, et al., including LANDCADD, among the earliest software aimed directly at landscape architects.) MACDOUGALL's (1984) seminal *Microcomputers for Landscape Architecture* included code for cut-and-fill calculations, and featured on its cover a crude representation of landscape (landform and vegetation) generated on a dot-matrix printer.

In the scientific community, software for dynamic systems simulations (e. g. Stella) became widespread, and was used for landscape models (e. g. COSTANZA et al. 1984). Speed and repeatable precision were the first attraction for many computer users; changing work habits for many were the unintended consequence. Impacts from this time were primarily on perception, analysis, and communication (from automated billing systems to the first digital cameras and 'photo-realistic' image manipulation for design visualization); design, construction, and occupation were still relatively unchanged. Early experiments in algorithmic design and robotic construction were already underway at MIT's Media Lab. GERO's (1980) paper explored "the potential contributions of simulation, generation and optimization techniques" – harking back to Simon's concern with optimization; and presaging the emergence of 'generative' algorithms to come. The primary participants at this time were building architects and architecture; landscape architects were slower to catch on, partly because landscapes are large, curvy, complex, fractal, and fuzzy, compared to building architecture – which may be

characterized as 'mostly rectangles', at least at that time – and computers' processors, memory, and algorithms were still too slow, small, and inadequate to the job. GIS was able to continue to flourish during this time, largely by representing landscapes as rectangular arrays of pixel values (e. g. digital terrain models and satellite landcover images.) These developments were almost entirely about representation, communication and analysis, and to some extent design; but no digital landscape features or construction robots.

1.4 'Internet': 1991-2006

The emergence of the Internet, fueled by the increase in power and availability of computing devices, network infrastructure and network protocols, brought the next qualitative transformation to the digital landscape. Larger CRT and then LCD screens and higher resolutions made digital imagery more attractive to landscape architects, and made desktop GIS, 3D CAD, and digital video more feasible and commonplace. The awareness of the impacts of these developments was visible in VON WODTKE's (1993) *Mind over Media: Creative Thinking Skills for Electronic Media* (note: still 'electronic', not yet 'digital'…) and ongoing developments at MIT's Media Lab (e. g. MAEDA's (2004) *maeda@media*). Early experiments in VR technology were expensive and cumbersome, but beguiling. Digital landscape architecture was consumed by experimentation with digital representations and to some extent algorithmic form-making, as documented in ERVIN & HASBROUCK's (2001) *Landscape Modelling: Digital Techniques for Landscape visualization*. The first international Digital Landscape Architecture (DLA) Conference was held in Bernburg, Germany in 1999, and in its early years primarily featured a wide range of reports on teaching or research (only rarely practice), using image processing, CAD, GIS, digital video, dynamic simulations, AR/VR, and other emergent technologies including digital fabrication.

By this time, impacts on landscape architects were no longer just on perception, analysis, communication; early impacts on occupation, design, and construction were already evident. Design and representation of processes, not just forms, became both possible and fashionable.

1.5 'Ubiquitous Computing': 2007-2020 (Present)

In 2007, Apple introduced the iPhone: the next quantum jump in the digital landscape. Because such devices are carried by individuals all the time, and are increasingly capable of being a 'personal digital assistant' in many life realms, from banking, to recreation, to travel, culinary, and recreational pursuits – also replacing a separate camera, notepad, or wallet – this has sometimes been called the era of 'Pervasive Computing' (and of 'pervasive surveillance', a serious concern but not a major topic here). Mobile phones have an array of sensors embedded that make them useful and responsive, and the same technology enabled the emergence of other sensor-dependent technological innovations, including notably autonomous vehicles, from airborne drones to self-driving motor vehicles, and a wide range of autonomous 'robots'. Now almost any interaction with almost any landscape, urban or wilderness, can be digitally mediated.

Thematically, occupation and perception of the landscape have been most heavily impacted, along with communications and construction. A wide range of literature – including WALLISS' (2016) *Landscape Architecture and Digital Technologies: Reconceptualising Design and Making*, CANTRELL & HOLZMAN's (2016) *Responsive Environments* and CANTRELL & MEKIES' (2018) *Codify*, CARPO's (2017) *Second Digital Turn*, AMOROSO's (2012) *Digital*

Landscape Now, WESTORT's (2016) *Coding Landscapes* and many others – have all sought to address the profound influence of digital technologies on landscape architecture, theory, research, practice – and ultimately, on digital landscapes *per se*. In the larger socio-technical context, artificial intelligence (AI), especially 'machine learning' and 'deep learning' has come widely into common use, and more and more machine actions seem less like mindless robots and seem (and are) more personified and personalized. Our human occupation of the planet, and our perceptions and analyses and communications are all heavily digital-technology-dependent; we are increasingly surrounded by 'Industry 4.0' and the 'Internet of Things' (IoT); construction is increasingly more digitally-mediated every day; and design, while still deeply mysterious as a cognitive activity, is increasingly 'computer-aided', even for landscape architects.

1.6 'Enormous Data' and Cyber-Physical Systems: Present – Future

'Big data' and machine learning are already watch-words of contemporary cyber culture, affecting everything from retail-shopping surveillance, to genomics and crowd-sourced environmental data gathering. Big data will surely become only bigger – even 'enormous'; and machine learning is increasingly becoming 'deep' learning (not requiring structured data, as required by early AI learning algorithms.) Cyber-physical systems will become ubiquitous, as everything in the built and natural environment will be capable of being connected to a great network of networks, providing the enormous data and feeding the deep learning; and the cyber-physical may well evolve into cyber-organic, where living animals and plants have digitally enabled prostheses which will modify their appearance and behavior. These developments will doubtless have implications on design processes and technologies; and therefore, on landscapes and even our definitions of landscape. These 'bionic' landscapes will require their own critical analysis, and a subsequent DLA article, or several.

2 Tentative Taxonomy of Digital Landscapes

2.1 Proto-Digital Landscapes with Electro-Mechanical Elements

Olmstedian landscapes have long featured various analog electro-mechanical elements: early mechanical automata, lamps along pathways, possibly with timers; fountains with pumps and valves and sequenced choreography; irrigation systems; security locks and gates; etc. Although originally non-digital, all of these control systems have gradually become digital, with ever more sophisticated control mechanisms, programs, and responsive behavior.

It seems clear that some landscapes and some landscape architecture (however they are each defined) are 'digital' in some way; and others are not in any way. But this binary distinction is not enough; for there are 'kinds' of digital landscapes. Following on the chronology above, considering the several ways in which digital approaches and technologies may manifest in and as landscapes, and bridging the two possible interpretations of 'digital landscape architecture' originally mentioned, I propose a simple taxonomy that distinguishes seven distinct (although also necessarily overlapping) kinds or 'families' of digital landscapes, in a roughly linear progression from the 1960s to the present (Table 2).

Table 2: Seven Kinds of landscape in the Taxonomy of Digital Landscape Architecture

Digital Landscape Kind	Dates
1. Landscapes w/Documents digitally produced	~1960 – present
2. Virtual (Non-Physical) VR Landscapes	~1970 – present
3. Algorithmic Landscapes w/Designs digitally conceived	~1980 – present
4. Physical Landscapes w/Construction digitally enabled	~1990 – present
5. Augmented Landscapes w/virtual digital AR elements	~2000 – present
6. Cyber-Physical Landscapes containing physical digital elements	~2010 – present
7. Bionic landscapes	Future ??

2.2 Landscapes w/Documents Digitally Produced: 1970 – Present

The LCGSA's work on software was used in the mid 1960s by Professor Steinitz at Harvard's GSD in the seminal 'DelMarva' land planning studio; arguably one of the very first examples of post-Olmstedian digital landscape architecture: design conception, representation, and communication were all influenced by early digital techniques.

By the 1970s landscape architects working for the US Forest Service were using digital landscape visualizations, and GIS was becoming an established industry, reinforced by early satellite remote-sensing platforms and using capable digital computing tools. Digitally-driven pen plotters were capable of producing maps and drawings that had previously been drawn by hand. Today, almost all relevant documents for almost all built landscapes are completely digitally dependent, from digital photographs and word-processed PDFs to BIM data sets.

2.3 Virtual (Non-Physical) Landscapes: 1970 – Present

Virtual landscapes are representations that may draw upon the characteristics of real landscapes, albeit with graphic abstraction, and may be intended to mimic and evoke non-existent or unbuilt landscapes that *might* exist – for example Repton's famous water-color overlays from the 1800s – but also may also be intended to disregard conventions and constraints of real/buildable landscapes, for aesthetic or conceptual/ideological reasons – for example Bruegel's fantastic/dystopian landscape paintings from the 1500s.

In this sense both the early raster landscape representations produced in Steinitz's DelMarva study, and just as much the vivid CGI landscapes in the movie *Avatar*, count as virtual landscapes. They may be simple line drawings done in CAD, or they may be seen only while wearing special stereo-vision VR Glasses (e. g. Oculus, HTC Vive, et al.); they may be 'realistic' or 'magical' or anything else; and they may or may not be digital, though clearly a growing majority of them are. The idea of a 'digital twin' to any real artifact, environment, or system being valuable for documentation, analysis, and for design explorations, is appealing, and has found wide acceptance.

These kinds of digital landscapes can, by virtue of being virtual, stretch or challenge our idea of "what is a landscape?" and so they are a particularly interesting and also vexing new kind of landscape. Amongst virtual digital landscapes, there is doubtless a possibly interesting deeper taxonomy of sub-kinds, not further explored here.

2.4 Algorithmic Landscapes w/Designs Digitally Conceived: 1980 – Present

Digital landscapes may be designed not just by producing representations using drawing software, but also by coding; using algorithms, mathematics, logic, databases, and computer graphics technologies to create virtual landscapes. Databases may provide input to the design of certain dimensions, capacities, and features; parametric variation may be employed to explore alternatives; random generation used to introduce unexpected perturbations, and so on. Ever since the first CAD system, programming languages have been available to control the generation and production of shapes and forms, and with clever programming, even more complex assemblies and terrains. This has been generally more evident in academic and research work (e. g. GENERATIVE LANDSCAPES n. d.) than in practice, but that is changing.

2.5 Landscapes w/Construction Digitally Enabled: 1990 – Present

Robots in factories appeared in the 1960s; by the1990s they were in the field, in the form of autonomous construction vehicles, including trucks, loaders and bulldozers; which were in turn dependent upon terrain data represented and DEMs and TINs, and on precise GPS-based location and motion control. Today it is increasingly ordinary for construction scheduling and logistics systems as well as communications and documentation to be dependent upon digital devices and databases.

2.6 Landscapes Augmented by Digital Elements: 2000 – Present

Virtual landscapes (2.2 above) and VR technologies offer great range for imagination and exploration of alternatives, even seemingly impossible proposals; but also suffer from being unconstrained by physical reality, gravity, complexity, and etc. By contrast, augmented reality (AR) technologies combine perception of the real world overlaid by virtually superimposed elements. Consequently, they automatically give physical context to new design proposals, and can use new proposals to highlight and accentuate real-world elements. Still in its infancy, this approach offers great promise to landscape architects. Their physical and optical mechanisms – ranging from simple holders for camera-enabled cell-phones, to Microsoft Hololens headsets – are necessarily complex, and still crude, but as their ergonomics, accuracy, and resolution inevitably improve, AR seems likely to become a routine expectation for visualization purposes, especially in public, contested, and visually fragile landscapes. From in-situ visualization of sea-level rise to the crowd-sourced Pokemon Go game-environments, such digitally augmented landscapes are increasingly part of life.

2.7 Cyber-Physical Landscapes (Containing Digital Elements): 2017 – Present

Cyber-Physical Systems (CPS) are integrations of computation and physical processes – a technological development already under way in various industries and environmental applications, such as autonomous vehicles, for example. Sensors, algorithms and actuators are the manifestation of the simple 'input-> processing -> output' model that characterizes cybernetic systems. These are still rare in landscape architecture, although sensor-actuated water fountains and irrigation systems are commonplace; and sensor-actuated lights and entrance gates are familiar. More interesting/complex integrations are beginning to appear, for example the weather-responsive light sculptures from Stoss Landscape Urbanism, reported in ERVIN's (2018) *Sensor-y Landscapes*.

These kinds of sensor-y landscapes represent the new frontiers in digital landscape architecture, and will define the term 'digital landscape' as their manifestations appear in the next years and decades. How sensors and actuators are deployed and act along with natural terrain and organic plants – whether they are just like 'furniture' or 'mechatronic equipment' in any old landscape, or whether they can bring new dimensions to landscape conception and experience – is still to be seen. It seems likely that the digital nature of these devices, and so their ability to be connected to a network, and to various forms of artificial intelligence, will bring all-new opportunities and challenges to landscape designers.

2.8 Bionic Landscapes: (Future ??)

The term 'bionic' dates to the late 1950's when, along with 'cyborg', it was coined to describe a biological organism, having been enhanced by electronic or mechanical parts. More than just prostheses, however, the term implies a kind of radical union between the biological and the electro-mechanical. This union is at least creepy and even detestable to some – the kind of monster epitomized by Dr. Frankenstein's – and fascinating and even beautiful to others.

Robotic terrains and cyborg plants are unfamiliar to us as of yet; but new advances in geo-planetary engineering, such as the kinds of barriers being envisaged to defend against sea-level rise, coupled with advances in genetic engineering and nano-scale materials that may yet lead to the development of a kind of artificial leaf or plant for efficient solar energy harvesting, seem ever less fanciful every day. The 'SuperTrees' of the Gardens by the Bay (GARDENS BY THE BAY n. d.), in Singapore, are recent examples of cyber-physical systems: tree-like structures with solar energy and rainwater collection systems, that provide mechanical habitat for orchids and bromeliads much like biological rain-forest trees. Though these are still only mechanically coupled – not biologically merged – they seem to presage coming bionic landscapes. These future bionic landscapes will require their own critical analysis, and a subsequent DLA paper, or several…

3 Discussion

In addition to this chronological and thematic re-telling and prognostication, it's important also to consider the impacts of these developments. The emergence of 'digital landscapes' in recent history raises questions about the definition and meaning of "landscape". Is a traffic intersection with autonomous cars, pedestrians sporting wearable digital devices, and street-lights connected to the internet and to a controller connected to the weather service, a "landscape"? Worthy of a landscape architect's attention? What dimensions of such landscapes can be designed? How and by whom? Is a representation of a landscape (e. g. a 'VR' world full of trees, rocks, rivers...) itself a landscape? Worthy of a landscape architect's attention?

It is also important to consider the value and utility of such landscapes. In STEINITZ's (1992) six-part "Framework for Theory", digital manifestations may appear in each of the six models: Representation, Process, and Evaluation; and Change, Impact, and Decision. The analog version may use paper maps, sketches, and diagrams, hand calculations, and in vivo meetings and discussions; while the digital version will have GIS data, 3D models, spreadsheets, algorithmic designs, dynamic simulations, and on-line voting. Both ways will work, and what's most interesting in this context is to evaluate what special characteristics (advantages and disadvantages) each medium brings to play.

The proponent of digital techniques may well argue for the advantages, in speed, complexity, thoroughness, and malleability of digital workflows and techniques; but there is little evidence that any such landscape project or product is necessarily 'better' in any measurable way. Any claim for 'better' needs to specify 'by what metric', and there are so many metrics of landscape quality – and so little agreement on their definitions or relative value – that such a claim will doubtless engender vigorous examination, criticism, and counter-argument.

4 Summary

The first half of the history of digital landscape architecture (say, 1950-2000) involved only the first of two possible interpretations: digital approaches to (the many aspects of) (the practice and manifestations of) conventional/Olmstedian landscape architecture. Digital technologies were applied almost entirely motivated by perceived or promised economies, or new capabilities, to create representations for landscapes otherwise untouched by the early digital revolution. Most of the landscapes designed and constructed in these times would have been fully recognizable by Frederick Law Olmsted or most other 19th century citizens, except perhaps for some advanced structural and other technologies, including some electrical components (e. g. motors, pumps, lights), automobiles, and the fashions worn by visitors.

In the second half of our history (say the last two or three decades), the very acts of designing and the elements constituting landscape design have been modified by digital technologies and phenomena: the former by 'ubiquitous' or 'pervasive' computing', from crowd-sourced information to algorithmic design approaches including optimization, algorithmic generation, and parametric variation; the latter by the emergence of the Internet-of-Things, autonomous vehicles, a wide range of environmental sensors, and dynamic digital control systems. Increasingly today, AI techniques including deep/machine learning are also beginning to emerge and to influence design approaches and built environments. Trees, rocks, and rivers, as well as motors, pumps, and lights are all still present; but they are increasingly involved in hybrid cyber-physical systems, and enmeshed in digital control systems that enable a wide variation of dynamic effects previously unimaginable (multi-spectral LEDs that change colors under computer control, e. g., or sensors responding to crowds, mass, and motion.)

In the 21st century we can expect not only new digital approaches to 'conventional' landscape architecture – as well as a demand from nostalgic and deeply-human desires for purely analog, Olmstedian landscapes and landscape experiences untouched by digital influences – but also the blossoming of an endless variety of truly (post-Olmstedian) digital landscapes, studded with sensors, embedded in interconnected networks, responsive to a wide range of environmental factors and human and other inputs, informed by enormous data, deep learning, and cyber-physical systems, and evolving inevitably towards bionic landscapes of one sort or another.

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