

A Parametric Approach to 3D Massing and Density Modelling

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Abstract. *This paper addresses the current void between social agendas, environmental criteria and design methodology in urban planning through the implementation of new computational systems. It considers the application of digital design tools such as GIS and parametric systems towards more efficient and effective design solutions. The digital design methods have been developed and tested within Grimshaw Architects Design Technology Group on both Australian and international urban development projects. A methodology for the use of parametric design for urban design development is suggested for defining, simplifying and categorising planning and design strategies. The following tools are a means of generating urban design concepts as digital forms in order to better inform the designer during the design process.*

Keywords. *Parametric; Urbanism; Sustainability.*

INTRODUCTION

Our population is exponentially growing at an unprecedented rate. Despite this trend, the housing market is struggling to keep up with increasing demand. There is currently a yearly shortfall of 40,000 houses Australia wide. Alarming, this shortage is expected to increase to 6 million by 2056. [1] This demand is placing an extraordinary strain on our urban centres with half of the country's population now living in cities. (Weller 2009) Higher density environments have long been recognised as a means of achieving more effective and sustainable cities. (Batty 2003) More efficient use of space and resources along with more integrated amenities and community are sustainable goals that are not currently met in Australian cities. As a result of this opposition, the sprawling, high consumption suburbs continue to radiate away from our urban centres. How we respond to these contemporary urban problems through our planning and design approaches will ultimately define the quality of life within our growing cities.

The inadequacy of traditional urban design techniques and standards is widely recognised as insufficient for creating successful urban developments. (Lowry 1965) In order to effectively manage our built environment, we first need to address the growing misalignment between current social aspirations and the working methods of urban designers. There has always been a divide between practiced design methods and social agendas, (White 2007) but at the same time the two are symbiotically and cyclically linked. A culture's milieu can impact on technological development (Mumford 1934) as new methods are formed around those aspects of ideology that can be quantified, analysed and applied within practice constraints. By the same token, these working methods often transfer certain stylistic qualities that, when applied to a built fabric, can influence the way in which a community operates and interacts. The problems we face today are not new in this regard, but are merely exacerbated by the increasing scale, population, economy and

governance in our built environments. When compared against contemporary understanding of the immensely complex relationships that exist in our cities as well as the multitude of ideological urban theory it is clear that our current methods of design are no longer adequate for addressing the required information at hand. This inadequacy can be addressed through the defragmentation of the working methodology to identify key steps in physical planning relationships and urban governance that can be positively informed by emerging digital information and design systems.

This paper aims to address the current void between social agendas and design methodology through the introduction of digital design tools such as GIS and contextual data bases along with discrete parametric analysis applications. All of the digital design methods have been developed and tested within the Design Technology Group in Grimshaw Architects on Australian and international urban development projects. The following tools are a result of this imbedded research and have been developed as a means of generating urban design concepts as digital forms in order to better inform the designer during the design process.

MASSING AND DENSITY MODELS

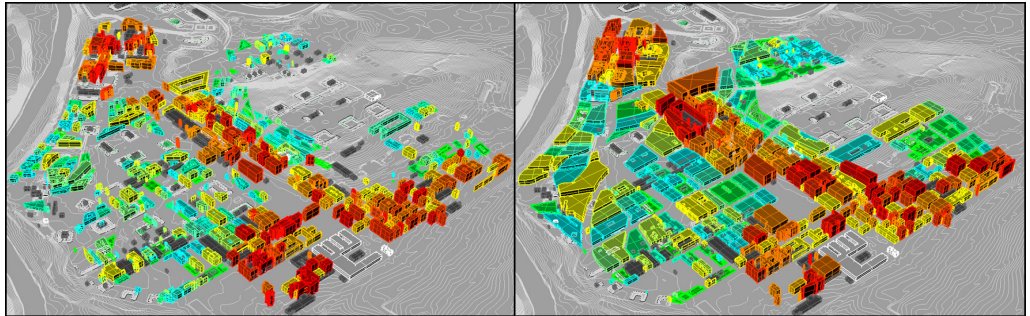
The initial phase of masterplan design is a crucial for setting the correct balance between built mass and open space as envelopes to define the subsequent detailed design stages. The answer to this balance is contextually specific and therefore has to be well informed by existing conditions, potential opportunities and future aspirations for the design. In order to meet these varied needs, the initial planning phase needs to be defragmented into manageable design deliverables that can address different contextual drivers. These can then be tested through parametric modes of information driven design, built form analysis and iterative optimisation tools. By simplifying the process into deliverable sets, the process can be managed more efficiently so that both computational and analogue design methods can be utilised more appropriately. The solutions

to several of these functional problems have been sought through the application of digital tools such as GIS data and parametrically defined modelling systems. However, there appears to be a significant discrepancy in understanding what these tools can positively provide to the designer and the design process within practice constraints.

This paper considers several contextual issues in a massing and density scheme and outlines the resulting parametric design tools, methods and outcomes of the process. The computational tools are not intended as a way of generating urban designs, but are a means of sorting large quantities of data to find what is relevant for informing a designer's contextually specific vision. The later stages of detailed urban design still suffer from serialisation and standardisation when parametric definitions are used for the models generation. (Vincent 2010) Parametric Urbanism should not be viewed as a means of designing on behalf of or replacing the architect or designer. Instead, parametrics should be viewed as a support tool that can help to inform the designer in the decision making process. For this reason the following research focuses on the initial phase of design that deals with site, massing and density through the use of GIS and parametric software.

This paper will report on the design methods that have been developed to produce initial 3D massing and density diagrams. These methods have been developed in two distinct phases of digital processing in order to optimise both designer and computer input. Each of these phases contains a set of sub categories that have been identified as common problems that are encountered in traditional design workflows. These problems are generally defined by their high level of complexity, labor time and their ability to be refined into simple principals that can be expedited through the use of digital processing. In order to ensure a constant workflow through these design phases the initial GIS information has been converted into formats that can be used by Adobe Illustrator, Rhino and the parametric plug-in Grasshopper.

Figure 1
Parametrically generated
massing diagrams.



The first phase design methods are a simple means of compiling and extracting relevant contextual data and using this as a foundation for diagramming initial conceptual ideas for a given site. The Second phase design methods utilise custom parametric scripting to translate the concept diagrams into digital massing models. (Figure 1)

These models can be generated with variable massing, density, height and other relevant planning restrictions as parameters to test multiple variations of a design diagram very quickly. Visual analysis, gross floor area values and land use percentages are all generated directly from this model. This level of impact analysis at this initial planning phase is crucial to the communication and validation of a design concept.

FIRST PHASE DESIGN METHODS

The first phase involves the compilation of existing site information and the process of analysing and responding to this data through a set of design responses. The following process has been developed in order to offer the designer flexibility to defragment the process into discrete problems that can be solved through parametric means while still allowing for intuitive and manual design responses. The key to this method is in the interface between ubiquitous digital data, human interpretation and response back into a digital representation. This process results in a more informed means of diagramming conceptual design aspirations in a form that can be later tested and critiqued through other digital systems.

Site information and analysis

Through the development of new recording software and sensor hardware, design teams now have the ability to collect or access huge amounts of data for specific tasks and fields of interest. (Bourke 2006) The resulting databases can record prevailing environmental conditions as well as track the movement of people, measure consumption of resources and pollution. These and other relevant contextual influences can be recorded over multiple timescales to accurately map out information in a number of different formats. The sheer quantity of some of these data sets has accentuated the need for new means of mining and utilising relevant information for architectural application.

Geographical Information Systems (GIS) are a management system for data that is gaining prevalence in urban design. (Gröger 2007) GIS offers a high level of data control for existing conditions which can set up a very strong framework for models demonstrating opportunities and constraint. The quality of the final 3D massing diagram is directly linked to the quality of this contextual data.

For the purposes of this case study a relatively manual process was used in order to extrapolate site information from the GIS database. This process involved selecting the desired information and exporting layers from the native GIS format into a master CAD file comprising of the layers of project data. This technique suited the level of information used in these tests but more automated data mining techniques are now being explored for extrapolating relevant information from larger databases.

In order to process the information in the master file, it was necessary to develop custom parametric tools capable of interrogating the model. Two of these initial strategies are the gradient analysis and the network path optimisation tools.

Gradient analysis was used analyse existing topography for its angle of incline. This was helpful in assessing the future potential for automotive, tram and train accessibility as well as planting zones and disabled access. An individual map could be produced to identify specific gradient range to flag

problem zones for each of the studies. (Figure 2) This aided in developing planning strategies that imposed as little resistance to the site as possible.

The Network optimisation tool was used to compute minimal path networks between a set of key points in and around the site. This digital tool is inspired by the analogue wool thread models by Marek Kolodziejczyk which looked at optimising de-tour path networks. (Schumacher 2009) As a digital model, these networks are calculated through the use of different line attractions between primary

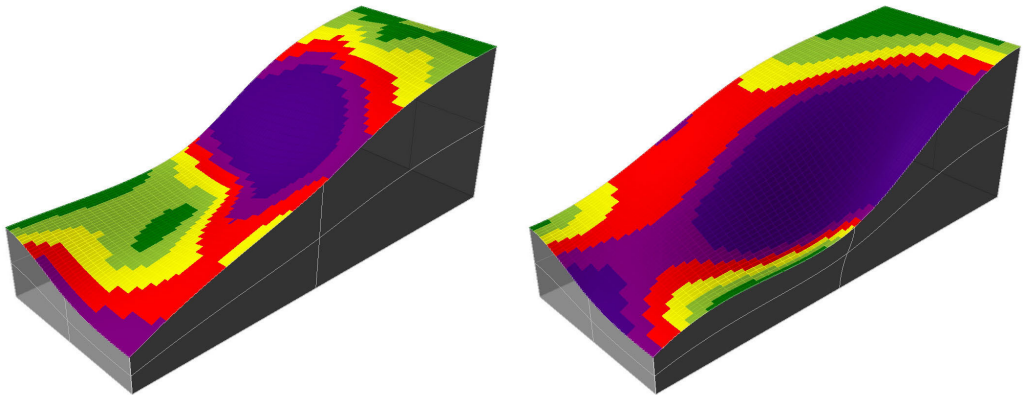


Figure 2
Gradient mapping results
across varying terrain. (Image
courtesy of Grimshaw).

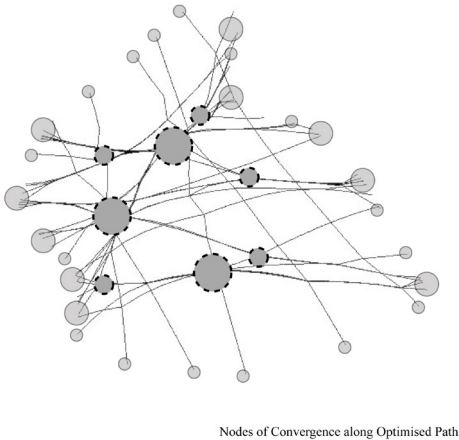
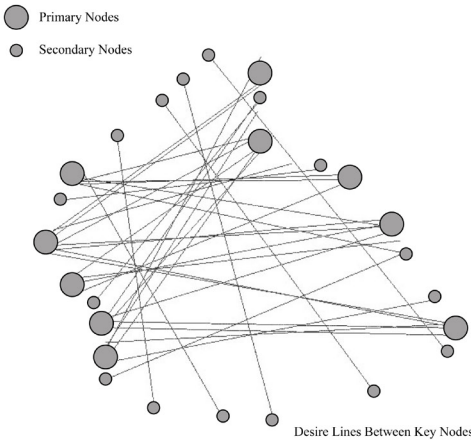


Figure 3
Desire lines deforming into
optimised detour paths.

and secondary desire lines. When animated, this attraction deforms the lines towards each other relative to proximity and attraction strength of surrounding lines. In this manner, an average route between desired points can be calculated. This method is not applied to determine road layouts in a literal sense, but instead is used as a means of extrapolating intersections between networks of paths that have been connected across the site from surrounding fabric. These intersections can be used to identify optimum positions for future hub development and higher density focal points of the masterplan layout (Figure 3).

These digital tools have been developed specifically to aid a single, discrete problem in the design process in order to give the designer freedom of choice in their application. These and other tools are still in development for the analysis of existing site conditions. Further research is being conducted into refining these digital data extraction and analysis tools and cut down the laborious processes of

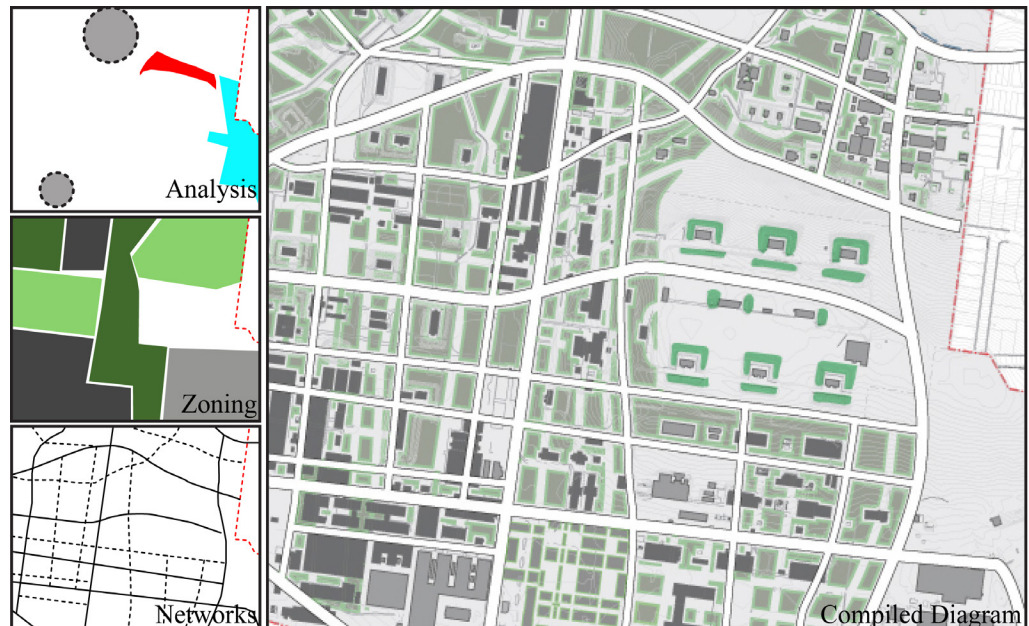
sorting and analysing data. The aim of this is not to eliminate human intervention through automated site analysis but to more effectively feed relevant information to the designer as the key decision maker.

Digital diagramming

Parametric systems have been programmed to recognise certain areas for analysis and then generate predefined responses that are dependent on the results. Although engaging from a technical perspective, this approach is inappropriate for addressing a broad spectrum of design issues and can often stray into the realm of geometric mastery rather than focusing on the issues that can have a direct and positive benefit from the application of digital tools. For this reason, Illustrator sketches overlaid onto the previously developed information model is still the preferred method for translating ideas into diagrams.

The reason Illustrator has been chosen as the platform for digital diagramming, as opposed to

Figure 4
2D Design diagram demonstrating street networks, block definitions and initial typology clusters.



more freeform sketch programs, is its ability to retain object identity and perform advanced manipulation such as Boolean operations and offsets. This setup allows for objects to be created under layer definitions which can be used to map out building typology. Colours and layers are later used in parametric massing generation (Figure 4).

The resulting line work can then be converted into CAD format. This is considered to be the diagram output as it is used as the basis for informing the parametric generation systems. This process can very quickly test a number of different ideas by producing a pictorial representation as well as simultaneously creating quality data for continuing the workflow. These detailed design diagrams are a hybrid representation based on a construct of existing conditions, parametric analysis and design aspirations. At each point in this process the decision making process is facilitated and accentuated by the digital tools as opposed to being lead by them.

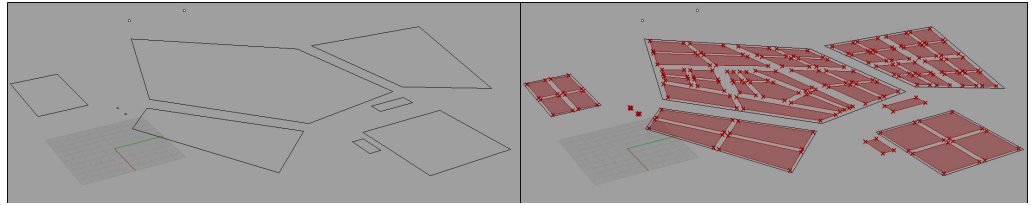
SECOND PHASE DESIGN METHODS

In order to create any form of massing model, there first needs to be a well defined set of control parameters. Percentage of open space versus density, range and type of public amenity compared to population volume and demographic are some such considerations that require some value range in order to define the scope of a development. This range is impossible to define introspectively or speculatively without data that has been derived from existing developments. The new design is therefore validated against ongoing development and success. To facilitate this need, a range of benchmarking exercises has been developed in order to tabulate the design aims and physical composition of a range of urban projects around the world. These statistics are then classified against the measureable success of their application and ongoing habitation. This benchmarking includes physical attributes of the developments, environmental performance as well as certain quantifiable elements of social aims and contributions (Figure 5).

Project	Bicycle parks	Students	Jobs	Densities	Occupancy Rate persons/dwelling	Population Density / Ha	Dwellings / Ha	Employment Density / Ha	Cars / Ha	Height	Building Footprint	Public Open Space m2/Ha	Private Open Space	Communal Open Space	Public Open Space	Open Space Overall	Public Open Space / person m2
BedZed, Surrey, UK			196			148	119 (12m2 per employer)	49	49	3	62%	3000	10%	10%	30%	38%	20
Frieburg, Vauban, Germany			600		3.1	132	52.63157895	16	20	2-4	21%*		25%*9%*		36%*		3
Hafen City, Hamburg, Germany			45000			87	46.03174603	357	206			2100			21%		

Figure 5
Segment of the benchmarking tool demonstrating some of the physical values of each of the developments.
(Image courtesy of Grimshaw).

Figure 6
Diagram outline conversion
to street networks and block
outlines.



From this database, a range of defining attributes can be extrapolated and applied in order to give the intended model a more carefully informed physical presence. A tool such as this can be very useful for comparing relative values or percentages in order to classify design decisions and their potential outcomes in a new development. It is important to remember that the differing scale of the benchmark developments is an important factor in the habitation and use of a design, so all figures still require a measure of interpretative analysis and design translation to be of use in a speculative design. This is not a definitive set of rules that can guarantee a directly comparable quality of urban space, but is intended to narrow the field of applicable solutions within the endless potential of a site. This, along with intuitive or aspirational goals for the development, the designer can begin to define a range of different parameters that warrant further testing at a more detailed resolution.

Plot diagrams

Now that a series of design diagrams have been created and along with a range of defining parameters, it is possible to start mocking up a series of block and street networks. This process uses the boundaries created in the diagramming phase and converts them into usable block areas. This is where the benchmarking parameters can influence the design and define the attributes that will govern different typology zones. Each of the footprint types are automatically collected by the parametric script and fed through the appropriate chain of massing control that correlates with the desired typology governance. The types are defined by the initial diagramming phase and can be used in this form with-

out any further manipulation of layers and types if desired. This initial division of footprint geometry is then carried through for the rest of the script for each of the subsequent functions.

This process passes the diagram object outlines through an iterative loop to refine the object footprints into usable block footprints. An iterative loop is a means of performing an action, validating it against desired values and then repeating the process with any negative results until all elements fall within the desired range. In the case of the block division, a control value is set in order to define the area of an ideal block size. The shapes that fall above this area value are then divided once through preset algorithm and compared back to this initial value. If the new blocks are still outside this range, they are fed back through the loop until they reach the defined value. All successful results are saved and fed through to the next definition at whichever loop they return a positive comparison (Figure 6). Values to control the block area, offset and street size can be independently controlled in order to achieve the required density and grain for each zone type.

Site massing

After the conversion of sketch shapes into building block outlines, another process can be applied to create 3D building masses. The final building envelope that is created in this stage is an offset of the initial block. The building height can then be extruded up from the new footprint. Once again, the offset and height ranges are defined by the benchmarking parameters and can be specific to each typology zone. The height of the mass is defined by a random number generator which gives the massing model a varied height. This generator is limited within a

mix/min range of overall heights and only generates integers of a variable floor to floor height value. The heights are therefore generated as full floors within a height range that is specific to its building typology. This tool gives the designer the control to set all types as a fixed height value or give any degree of variation between floors depending on the application. The random height is more for visual analysis and is not something that affects the area figures to a significant degree. The final product of this phase is a 3D diagrammatic massing and density model that simulates street networks, block subdivisions and open space as well as an indicative building mass (Figure 7).

In this instance, the script has been arranged to generate the massing model from building defined parameters such as street width, building to block offset and height ranges. As a result, the overall site figures such as Gross Floor Areas (GFA), Floor Space

Ratio (FSR) and Site coverage are the outputs. This process can easily be reversed to suit whatever input parameters have been determined as important during benchmarking phase. The main aim of this massing process is to use known parameters that correlate with desired design outcomes to inform the model and generate a 3D form that can be interrogated on performance at multiple levels of scale. The benefit of this method, as opposed to manual techniques, is that at each phase of development and design variation, both the input and output figures are tabulated (Figure 8).

The 3D model produced by this process can then be used as the basis for other forms of computational testing that are specific to the schemes design intent. This is intended as a feedback loop in the design method to continually test and validate ideas until a solution is agreed upon and continued into a more detailed design phase.

Figure 7
3D massing diagram
demonstrating three types of
parametrically generated high
density massing.

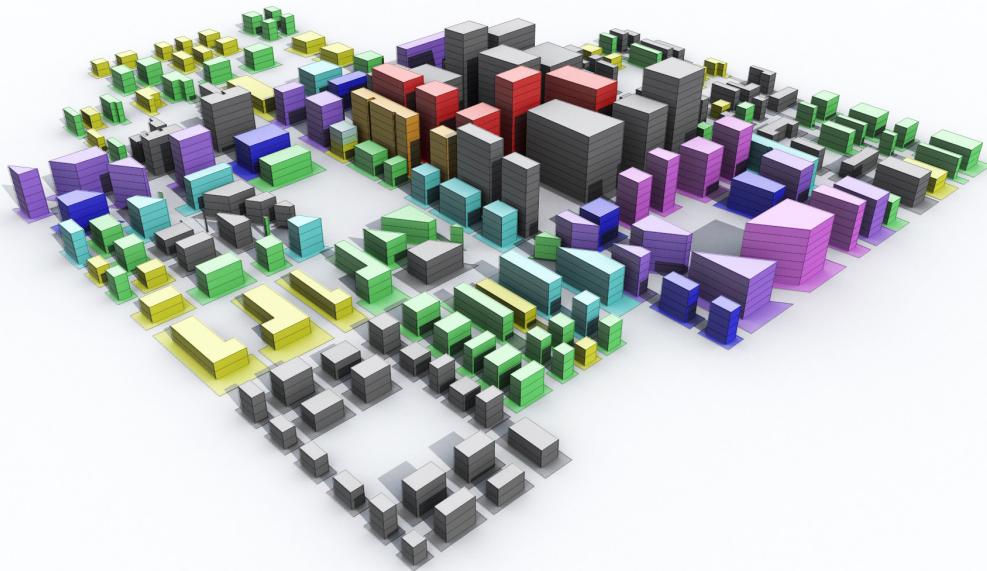
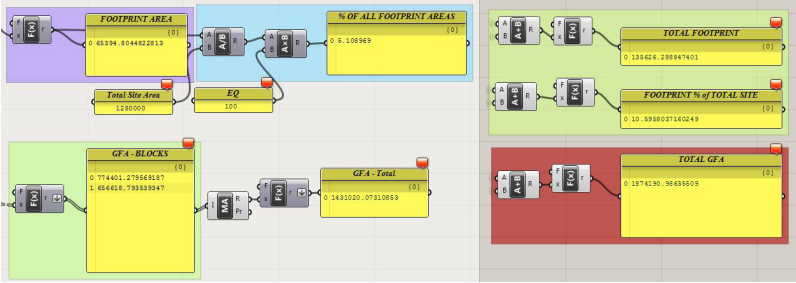


Figure 8
Script excerpt showing a selection of possible output figures from a single typology and the total sit.



CONCLUSIONS

This paper considers a method for approaching design through the use of new computational systems. This method has been developed in response to the increasing complexity in urban scale design and the inadequacy of traditional design techniques to produce a rigorous design response. The process is focused around the definition of parameters that can drive the design and support better design outcomes. This is intended to encourage design exploration while still maintaining a focus on a desired goal that meets environmental, economic and social standards.

Advantages of this computational approach include reduced design and build time, real time visual analysis with 2d planning and 3d visual representation as well a continuous automated output of relevant building figures. At each point in this design method the designers decision making process is accentuated by the digital tools as a means of addressing design outcomes such as contextual awareness, social betterment, economic viability and environmental stability. Without due diligence in understanding new technologies potential and developing new techniques for design development, rapid software development will continue to lead the design industry by the nose.

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