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System mash-ups: emergent crafts and rule-based approaches to design and construction

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Abstract

This paper will revisit the recent history of design and construction, scrutinizing—in parallel—conceptions of systemization and architectural craft. Within design and construction, technology is most commonly implemented to standardize processes; it is particularly dominant within management procedures. We will trace this domination from Vitruvius through to modern construction. We bring evidence to bear that suggests craft still remains a key constituent, particularly in our contemporary condition where technology is cheap, accessible and tunable. By looking at examples where craftsmanship manifests as the manipulation of a specific set of interactions between computing systems and software, this paper aims to provide observational evidence that prompts speculation of a return to the pre-enlightenment condition of architect as *'homo universalis'*. Where technology's influence extends beyond systemization of design and construction, rather the ability to *mash-up* disparate systems and software becomes a key constituent of the designer's process. Firstly we review the recent history of a rule-based approach to construction, starting with the early writing of Vitruvius through to more recent changes. This will include economic and technological developments that have influenced the current form of construction. Secondly, we will look at some of the recent initiatives that have been implemented to address the changing shape of the business and execution of construction; this will include methods of procurement and Modern Methods of Construction (MMC) such as panelized and volumetric construction. We review some current technological and collaborative developments in the design/making process that have been stimulated by technology and speculate as to their relevance within design and making. The findings challenge existing models for design and construction where technology is restricted to organizational management or digital fabrication; and draw attention to the influence of technology on the more arcane processes of creative practice.

Keywords: Digital, Design, Mash-up

1. RECENT HISTORY

The discussion of systemizing design and construction begins with Vitruvius. According to McEwen, Vitruvius was—until the eighteenth century—referred to by virtually all other authoritative architectural texts.[1] Within the historical context of design and construction what is of interest is how Vitruvius frames design and construction in the preface of book one of *The Ten Books of Architecture*.

I have drawn up definite rules to enable you, by observing them, to have personal knowledge of the quality both of existing buildings and of those which are yet to be constructed. For in the following books I have disclosed all the principles of the art.[2]

Vitruvius implies in the opening preface—of what was considered the authoritative source for design and construction of public buildings—that the quality of buildings can be contained in rules. The Ten Books on Architecture are exhaustive in establishing rules for building orientation, doorways, harmonics, climate, colours and celestial influence. According to McEwen, Vitruvius and this manuscript continued to be substantially influential within design and construction well into the eighteenth century. Beyond the eighteenth century McMordie and Rawlins have identified the propensity for rule-based construction continuing into the ninetieth century, when tradesmen used *pattern books* extensively[3]. These books contained set patterns for plastering and stonemasonry that could be reproduced as desired by clients.

The twentieth century brought with it a revolution in architectural design and theory. The sciences of space and the body could provide rules that could establish the size of windows required to adequately light and ventilate a room. Modernism provided a minimalist philosophy that reacted to the preceding trends in design and construction; no longer was Vitruvius a dominant authority. However, even in the radical aesthetics of Le Corbusier and his influential writings in *Vers Une Architecture*[4], we find in Le Modular the Vitruvian foundation of rule-based organisation. Pérez-Gómez might attribute this modern domination of rule - based organisation within architecture to the *Enlightenment*, referring to the rupture within art and science after which architecture became dominated by science and its foundation of systematic and predictable causal relationships[5]. It is then not unexpected that systemisation has evolved to underpin many contemporary design and construction practices.

1.1. RULE-BASED ORGANISATION IN DESIGN IN CONSTRUCTION

When Le Corbusier coined the phrase ‘machines for living’[6] he was referring to the metaphorical machine characteristics of purity of functional components existing in an efficient harmony. However, the machine-like efficiency and clarity practiced by architects in the design politics of these buildings—such as the Schröder House—were not reflected in the machine-like clarity of their construction. In fact, the construction of the Schröder House — like many of that period[7] — was traditionally rendered brick and mortar made to look like concrete. Arguably this undermines the functional and systematic ethos that

these designs were trying to establish, and it could be argued that the brick terraced houses (Figure 1) found alongside the Schröder House are more true to the machine politic in their construction, in terms of an economy of scale and material honesty[8]. The Schröder House and many other buildings in that style were often more difficult and less efficient to construct than traditional styles. This demonstrates how the adoption of rules, in this case for organisation and aesthetic purposes, does not necessarily directly translate into the efficient construction of a building.

Figure 1 Schröder House in context with traditional terraced house[9]

Still, even Le Corbusier could not have envisaged his machine for living ethos would have been so transformed. In the latter half of the 1900s the speculative construction industry developed a machine-like efficiency in the production of virtually identical houses. In light of the industrial standardised buildings of the speculative construction industry, Ruskin's concerns of industrialisation being dehumanising seem wellfounded, as do his criticisms of architecture adopting industrial principles and creating standardised buildings[10]. Efficiency and cost effectiveness in the form of increased profits or more affordable buildings are

typical drivers for change within the construction sector.

Continuing with the theme of efficiency, the construction industry seemed to draw inspiration from the standardisation and systemisation that was occurring in the automotive industry[11], which was streamlining car construction into efficient production lines of prefabrication and assembly. In doing so—particularly the Ford Motor Company—it was achieving an increase in profits and the creation of affordable products. Drawing inspiration from the Ford Model T prefabrication and assembly process, the construction industry looked to emulate the success in the automotive sector[12], before long it was applying the prefabrication and assembly to the construction process.

The transfer of prefabrication and assembly from the controlled environment of the automotive factory to the less predictable and less controlled construction site was not a simple transition. This was tragically illustrated in the UK at Ronan Point in 1968, when a domestic gas explosion on the upper floor of a residential tower block caused a catastrophic collapse[13]. Floor slabs experienced structural failure as the slabs above collapsed onto them, resulting in a cascade effect and structural failure from the upper to lower floors. The cascading failure of the floors at Ronan Point was attributed to flaws in the prefabrication and assembly process which proved much more difficult to monitor on a construction site than in a controlled factory environment.

1.2. SUB-CONTRACTING: THE NIKE MODEL

Figure 2 illustrates an unexpected phenomenon, productivity within construction (indicated as AEC standing for the Architectural, Engineering and Construction sector) falls as the manufacturing principles of prefabrication and assembly were implemented between the 1970s and 2000. While the manufacturing sector was steadily improving from the implementation of these changes, the construction sector was not. The principles as applied to the construction sector did not have the same anticipated effects they were having in the manufacturing sector. Similar changes that produce different results within the construction and manufacturing sectors suggests perhaps a fundamental difference between construction and manufacturing. If this were the case it would challenge continued attempts to compare and map processes from manufacturing to construction.

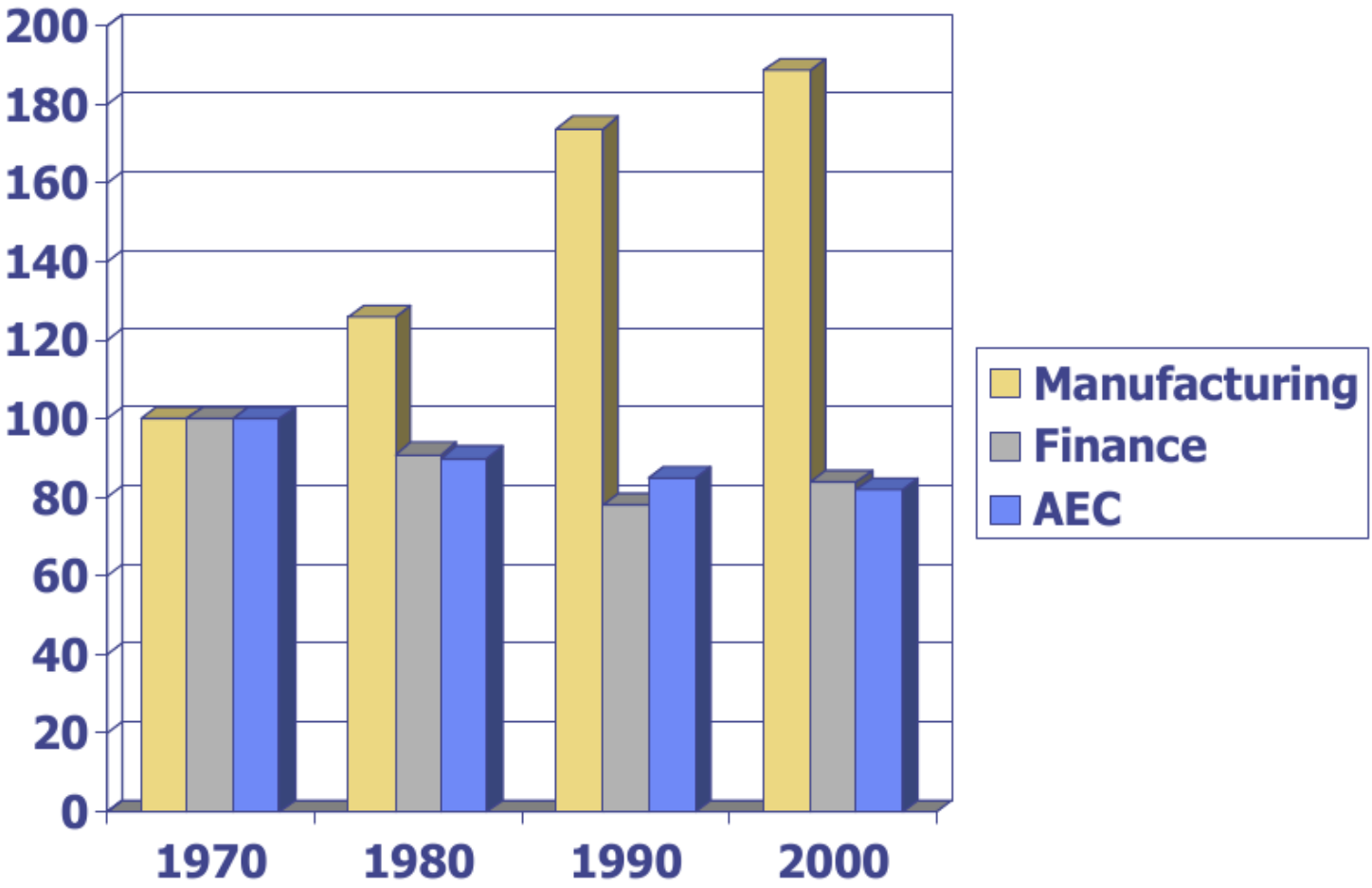

Figure 2 Productivity Index of US Sectors (copyright AIA April '03) showing drop in productivity of AEC sector

The practice of intensive sub-contracting has recently been referred to as the Nike model, referring to the athletic company that produces footwear and clothing. While Nike did not invent the practice of sub-contracting, the company developed it to unprecedented levels[14], which is why it warrants a brief discussion within the context of this paper. The manufacturing and finance sectors could sub-contract components of work elsewhere[15]; as a consequence of the lower labour costs from this sub-contracting, these sectors were becoming more and more productive as costs and direct employment figures fell[16].

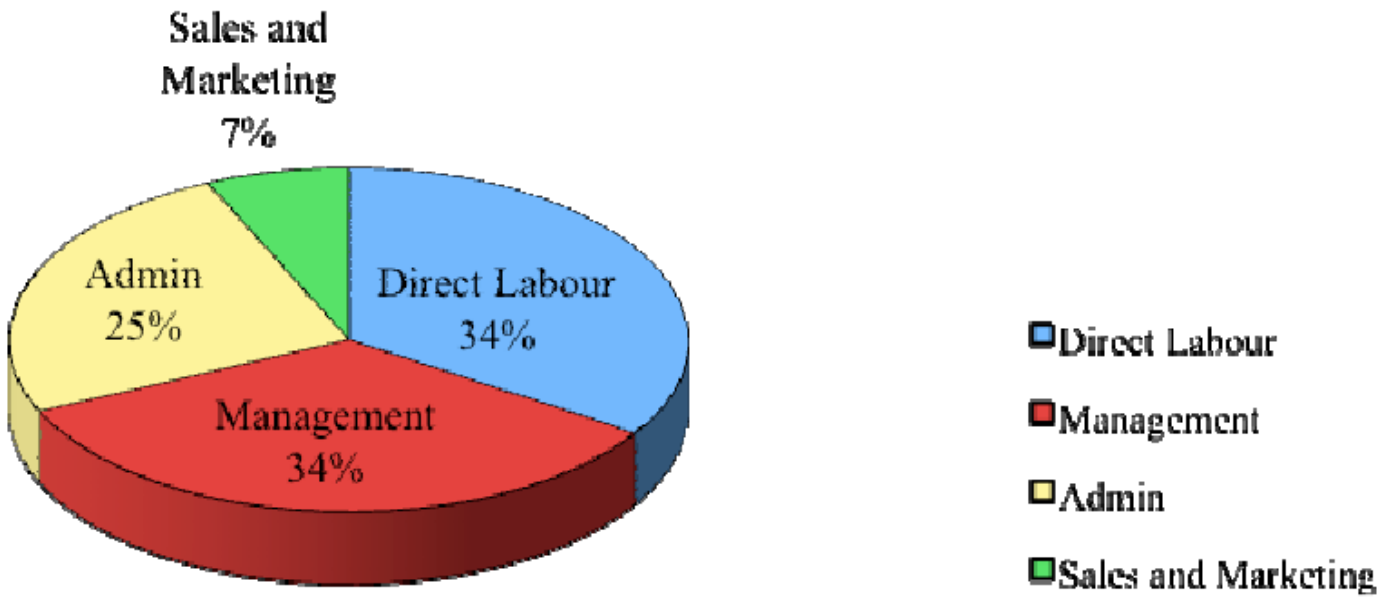

Figure 3: Typical construction organisation labour distribution showing direct labour only accounting for 1/3 employees

Construction has been driving to increase efficiency by focusing on the adoption of similar management structures to the manufacturing sector. Employing minimal direct labour and sub-contracting the maximum percentage of work to other organisations. The labour distribution in a medium sized UK construction organisation is illustrated in Figure 3, it reveals that only approximately one third of employees are engaged in direct on-site labour. The direct labour comprises of mainly interstitial employee roles for driving and general labouring duties etc. This is distinct from another third of the staff engaged with the management of the sub-contracted construction components; these are project and site engineers. The remaining employees such as accountants and quantity surveyors are invested in the administration of construction projects, with a small percentage dedicated to the sales and marketing of the projects.

1.3. THE PROBLEMATIC ALIGNMENT OF CONSTRUCTION AND MANUFACTURING

By drawing from the manufacturing model, a typical construction organisation will subdivide a construction project into individual sub-contracted components such as foundations, windows, cladding etc. By competitively tendering these components they can then achieve a lower construction cost, avoid large financial overheads and—as we have identified in the previous section—only employ minimal direct labour when it is required, thus decreasing overheads. However, Figure 2 illustrates these changes to the structure of construction organisations have not produced the same quantitative benefits when measured against the manufacturing and finance sectors.

As we have discussed, parallels are often drawn between construction and other sectors

that have achieved success from the adoption of manufacturing principles. In embracing similar principles, construction organisations have attempted to emulate that success. The failure to achieve that success draws attention to the differences — rather than similarities — between construction and manufacturing. Although manufacturing and construction are both site specific and each assembles components that have been manufactured elsewhere, the critical difference, as illustrated in the collapse of Ronan Point, is that the construction site environment cannot be controlled to the same extent as an assembly line environment. For example, construction sites can be radically altered by weather; they are usually limited to hours of daylight and sub - contractors may have esoteric methods of construction that conflict with others. The automation of prefabrication and assembly found within the manufacturing sector becomes problematic within the noise and furore of the construction site.

For the social critic Marx this process of automation is less about the potential prosperity it might facilitate in the form of more cost effective products, rather he argues that automation "transforms the worker's operations more and more into mechanical operations, so that, at a certain point, the mechanism can step into his place."[17] The construction of a building is often approximated as being a prescribed functional process; consequently certain activities within construction may inadvertently be devalued as others are brought to centre stage through this process of remodelling. Participants, processes and communications fragment as the construction sector adopts this manufacturing paradigm, communication technologies like mobile phones emerge to compensate and create new communicative possibilities that have yet to be fully explored.

It could be argued that the playing of a piano is the repetitive striking of keys and the playing of a banjo the repetitive plucking of strings. A construction site is perhaps like a piece of music, in a fluid ever - changing state of flux as it changes both temporally and experientially. However, the focus on the ceremonial ground breaking at the beginning of construction and **topping off** when participants regroup to celebrate the completion[18] is perhaps another suggestion that the construction sector invests little value in the process of construction having a greater focus on the finished product. Any craft that takes place between these two ceremonial markers is not appreciated, at least not in the same way that a piece of music might be appreciated.

2. RECENT INITIATIVES AND CHANGE

In this section we will review recent initiatives and the changes they have brought to

construction. First we will study influential UK government initiatives in the form of the legacy of the *Latham and Egan* Reports. The Government commissioned these two wide-ranging reports to propose recommendation for improving the construction process. We will begin this section by discussing the legacy of these reports and their effects on the construction process. Second we will review *restructuring* initiatives in construction, the implementation of partnering management structures that emerged from these reports and also discuss the influence of Modern Methods of Construction (MMC). There has been a recent resurgence of pre-fabrication, now often referred to as MMC. This includes panellized construction, where panels are fabricated off-site and delivered for assembly on-site. It also includes volumetric construction where a dwelling is conceptualised as a series of standardized volumes that can easily fit on a standard articulated lorry. These volumes are constructed off-site under controlled factory conditions, then brought to site and assembled. Third we will review initiatives in the form of *technological interventions* in the design and construction processes, before finally discussing recent trends in appropriating programming, mathematics and electronics within the design process.

Historically construction has evolved to accommodate its socio-political landscape and to embrace the new technologies that become available to designers and contractors. Through the 1980s and 1990s rapid computer software and hardware developments enhanced design, construction and management within the sector[19]. By the 1990s CAD (Computer Aided Design) software was maturing beyond simple Computer Aided Drafting with the integration of more sophisticated functionality, now assisting with project management and co-ordination during design and construction. While there is a fascination with these sophisticated technologies, it is worth noting that during the same period, mobile phones were clandestinely finding their way into design and construction. However, it has only been in the last five years that initiatives such as COMIT[20] (Construction opportunities for Mobile IT) are starting to explore the opportunities afforded by mobile phones within design and the construction process.

2.1. THE LEGACY OF EGAN AND LATHAM

Both of these reports refer to the manufacturing sector, either to suggest that lessons can be learnt from the systemisation and automation that has increased the efficiency of manufacturing or to suggest that construction can draw inspiration from manufacturing's higher level of coordination and the closer relationships that exist between the various

participants. According to government figures construction absorbs a substantial amount of money[21], in 1993 over 60% of this was in the form of government appointed contracts[22]. There are clear financial incentives for government to improve the means by which construction projects are procured and where possible to improve the efficiency of the construction process. The Latham Report published in 1994 and the Egan Report published in 1998 explored ways of improving productivity within construction, in the words of the Latham Report, "helping clients to obtain the high quality projects to which they aspire."

The specifics of each report varied, the Latham Report focused on the procurement and contractual aspects aimed to "enhance performance in a healthier atmosphere"[23] in construction. It aimed to contribute to closer working relationships. The culmination of the report was a list of recommendations, which included proposing systems to maintain better and more consistent working relationships such as "Co-ordinated Project Information"[24] and "Main Contractor and Sub-Contractor Lists."[25] The proposal of these recommendations has proved easier than implementation[26]. For example, although Latham proposed partnering—which will be discussed later in the chapter—as a procurement route that would contribute to closer working relationships, it was only after the Egan Report that it was widely implemented.

In its Executive Summary the Egan Report identifies the five drivers of construction as:

Committed leadership, a focus on the customer, integrated processes and teams, a quality driven agenda and commitment to people as key to the government's agenda for improving quality and efficiency[27].

More recently research by Amaratunga continues to cite efficiency as an important driver for change within construction[28]. With annual government targets to reduce construction costs and time by 10% and project defects by 20%[29], the Egan Report championed partnering amongst other principles to achieve this. Contrary to being a successful recipe for construction—although it has been widely adopted as a construction procurement method—Taylor and other critics argue partnering has produced mixed results[30].

2.2. RESTRUCTURING: PARTNERING AND MMC

New procurement methods such as partnering in the form of PFI and PPP and alternative construction methods such as MMC provide a variety of different structures by which

construction can be successfully executed. PPP (Public Private Partnering) and PFI (Private Finance Initiative) were forms of partnering proposed by Latham and Egan and championed by the government as a means of achieving improvements in the quality and efficiency of the construction industry through closer relationships. PPP is a contractual arrangement that would provide the participants with a more integrated team based structure thus facilitating closer relationships throughout a construction project. It was envisaged particularly for large public contracts, where a public body client would partner with a private construction organisation for the duration; as in the pathfinder projects[31] where local councils partnered with construction organisations for the extensive refurbishment of council houses. This arrangement would move away from the "formal communication and documentation between the project partners to a well structured, but more open and informal communication[32]." Egan cites several examples[33] including Tesco who saved 20% and other private companies who saved up to 30-40% of capital costs by implementing a partnering strategy with construction organisations. However, there has been debate regarding the substantial returns gained by private investors in such agreements and the suggestion that the cost of buildings procured in this way could actually be higher for the government and thus the taxpayer than traditional methods of contractual arrangement[34].

PFI also encourages the private financing of public construction projects, relieving the government of the financial burden. This has also produced mixed results. While the government acknowledged that it provides "greater certainty on the timing and on the cost[35]," Weaver casts doubt on whether there are tangible improvements to either the process of construction or the quality of the finished product[36]. A report to the House of Commons in 2003 echoes the concerns that the returns for a private investor—when engaged in this form of contractual arrangement — are unreasonably high. It also suggests that in 20% of cases the functionality of the buildings does not meet the intended design brief[37].

Criticisms of PFI are usually focused on monetary issues, either concerns that the private investor is gaining disproportionate returns on the project, or that the project costs more under PFI than under traditional government funding. However, the House of Commons report also suggests that both PPP and PFI forms of contractual arrangement are producing buildings that require modification shortly after completion. This does bring into question the suitability of these types of contractual arrangement to address design briefs and deliver functionally satisfactory buildings. PPP is not immune to further criticism either

and the design profession is often vocal regarding their diminished role[38]. Designers are often contractually bound within the PPP procurement structure to relinquish their design authority at an agreed juncture in the project. While these new arrangements have had an effect on the construction process and building quality, it is unclear from the evidence if it has been—on balance—a positive one. Current research by Jones and Kaluarachchi suggests that the absence of—and need for—trust is one of the main obstacles to these methods of procurement[39].

The *design and build* procurement method also challenges initiatives that are aimed at increasing the rigidity of design and construction. Within this structure the construction process advances iteratively, parts of the building such as foundations would be designed and built, only when required would the walls be designed and built. It was envisages as a much faster method of construction as design and construction were proceeding in parallel. It is also favoured by people wishing to self-build, abandoning a main building contractor and managing the design and build process also affords greater personal control of the finished building[40]. It is also seen to have higher environmentally sustainable credentials[41].

We also have cause to reconsider traditional structures of construction in light of MMC techniques such as volumetric and panelised construction. With both these methods considerable construction occurs off-site, and on-site construction becomes a process of assembly. Thanks to high profile design competitions[42] demonstrating the design potential when constructing with MMC, preconceptions of prefabrication and the legacy of Ronan Point have largely been forgotten. However, there are concerns that the speed[43] afforded by these methods of construction is at the expense of flexibility and the facilitation of design changes during on-site activities. We don’t presume to champion one particular strategy, rather we aim to illustrate that depending on the particular circumstance of construction and the value placed upon speed, cost and personal control, there are many alternative structures within which construction can be successful.

As the prescriptive formal communication structures and processes of construction evolve, so to do the informal. Within this context the current appropriation of mobile phones—for the moment at least—seems destined to be considered an unofficial communication device, which is used within these official communication structures. Within this framework mobile phones are typically brought to centre stage when they become problematic. However, it is unlikely their influence is limited to being exclusively problematic. It is equally probable

they exert positive influence on the construction process, yet when mobile phones fail to create a problem they go unnoticed. It is inconclusive if restructuring official systems of communication and process—as we have discussed—has produced positive results. This suggests that unofficial communication channels and technological interventions such as mobile phones may make profound and influential contributions to effective communication and thus to a successful and efficient construction process.

2.3. TECHNOLOGICAL INTERVENTIONS: 'VIRTUALLY' SEAMLESS MODELS

It was the Latham Report that brought the co-ordination of information during a construction project to centre stage. The development of CAD and in particular the notion of the **virtual building** model, which has been emerging over two decades seems to resonate with Latham's vision of co-ordinated project information. As projects continue to fragment[44] further into more specialised sub-contracted components, emergent technologies and software have the potential to assist with the increasingly complex and difficult task of co-ordinating fragmented information and disparate participants.

The construction sector continues to champion technology that enhances co-ordination, for the moment these technological developments seem to have converged into what is being widely described within the construction industry as BIMs (Building Information Models). BIMs are the most recent in a succession of software developments that aim to assist with the co-ordination of the various participants of a construction project, if it is provided with the appropriate data. In the early 1990s the ArchiCAD software from Graphisoft had already evolved beyond computer-aided draughting and could generate documentation such as sections, elevations and plans from a virtual three-dimensional building model. Subsequent changes to the virtual model would then be automatically reflected in the documentation. To obtain these benefits in practice it was necessary to invest more time in the creation of the virtual model. Although this was possible, it was not necessarily economically practical. By the late 1990s, teamwork functionality was emerging and assisting with the coordination of the distribution of work. Different parts of a building could now be assigned to different individual staff and the CAD software would ensure that the different participants did not encroach on each other's work. These individual changes would then be integrated in the overall virtual model.

More recent developments have been focused on information rather than documentation and BIMs have evolved promising to co-ordinate information from engineers, architects and quantity surveyors in a holistic manner. The construction sector is clearly excited by this potential, however the BIM methodology also has its critics. Chris Yessos, the CEO of

autowdeswsys has critiqued the limitation of BIMs and suggests they limit design freedom. His criticism is that in its current form BIM methodology can only be applied to designs that are simple in their geometric form, thus employing such systems in the design process could potentially restrict design[45]. The implication being that even if BIMs live up to expectations and relieve us of mundane tasks within design and construction, this relief is potentially at the expense of the creative process of design and construction.

By attempting to emulate manufacturing the construction sector has continued to strive for more rigid structures and systemisation within design and construction. However, statistical surveys provide no conclusive proof that construction projects implementing these changes improve either their productivity or efficiency. Contractual structures, such as PFI and PPP create more fragmentation of the design and construction team and process. Consequently the process requires more complex coordination and those charged with coordination resist deviation from the established process. However, techniques such as design and build and MMC demonstrate that a variety of structures for construction exist that suite different programmatic needs that place dissimilar values on design freedom, speed and cost. Virtual modelling software has resulted in more elaborate design descriptions and an increase in the volume of construction information. The trend in technological development continuing to increase rigidity during design and construction has prompted Yessos to argue that achieving these organisational and management aims may be at the expense of creative freedom within the working practices of design and construction[46].

2.4. DESIGN AS MASH-UP

Design and construction practices do not seem immune to exhibiting the behaviour currently described as 'mash-ups.' This is the process of taking one or more music tracks and 'mashing' them together; the metaphor evokes a more *ad-hoc* and crude methodology than 'mixing'. Crudeness and approximation are synonymous with the early stages of technological and mechanical innovation. The clunky prototype is highly romanticised in popular culture, in the popular film Iron Man, the first Iron Man suit built in a cave with crude tools is perhaps an example *par-excellence*. As technology percolates deeper into design and construction practices, we see design benefit from cross-pollination between technological innovation and design. One manifestation of this is architects experimenting and innovating with crude programming, manufacturing or engineering techniques. An *ad-hoc* proof of concept later evolves into a refined and robust architectural proposition. The Falkirk Wheel boatlift in Scotland is perhaps one such example, where the mechanism was

prototyped by the architect with Lego to demonstrate the concept to the client.

Increasingly programming is featuring in architecture; the Beijing 'Water Cube' being an archetype that is based on 'voronoi' mathematical tessellations. Voronoi is a mathematical process that subdivides 2D or 3D space into smaller areas by using points within that space. The points are used to generate lines to divide 2D space, and in 3D space the lines are used to create surfaces to subdivide the space. Although the resultant geometry—as with the Water Cube structure—can look random or organic, it is actually based on a robust mathematical process. Rather than being inaccessible this process can be facilitated by widely available software. The following example was used at an architecture open day at Auckland University to demonstrate the use of computing in design and construction. Figures 4 and 5 are screen shot from the popular CAD software Rhino; a freely available voronoi script[47] was used to divide the basic form and generate the complex geometry. This was then transferred into other software for—in this case—creating paper cut outs (Figure 6) before finally being reassembled (Figure 7). This workflow is based on design work by Josh Stewart, Patrick Loo and Sebastian Hamilton while at the University of Auckland, and it points to innovation though sensitivity to selective and critically considered hardware and software processes or 'mash-ups' within their design/construction process.

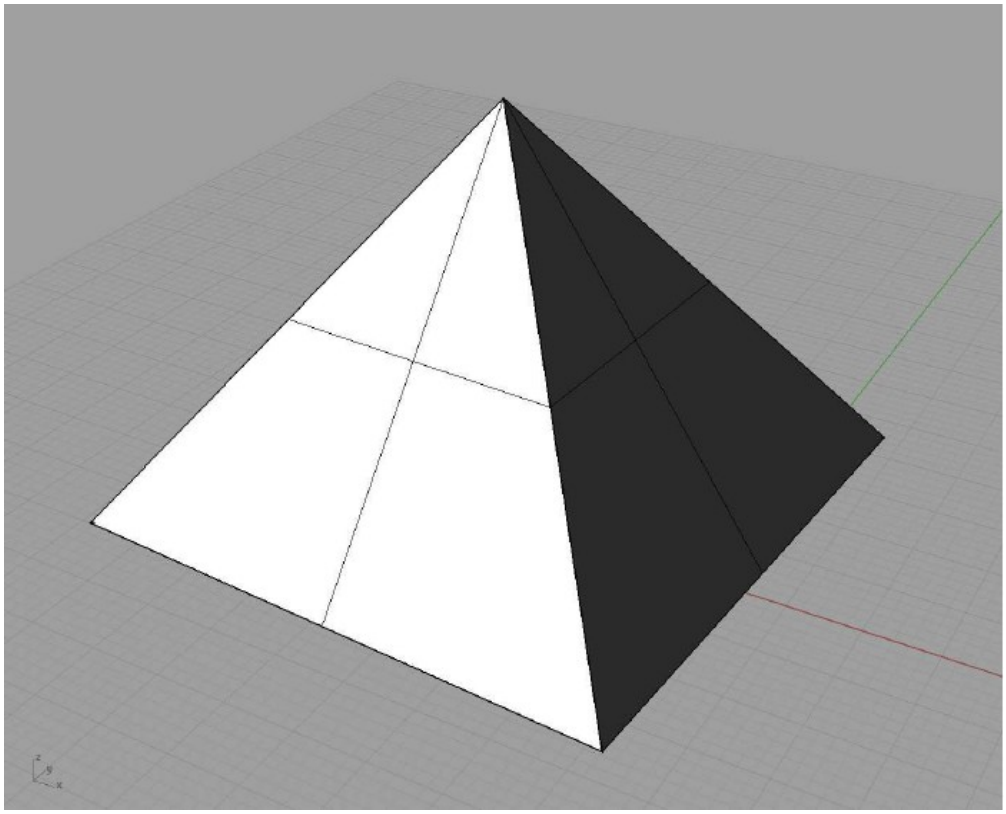

Figure 4 Unaltered form in Rhino software

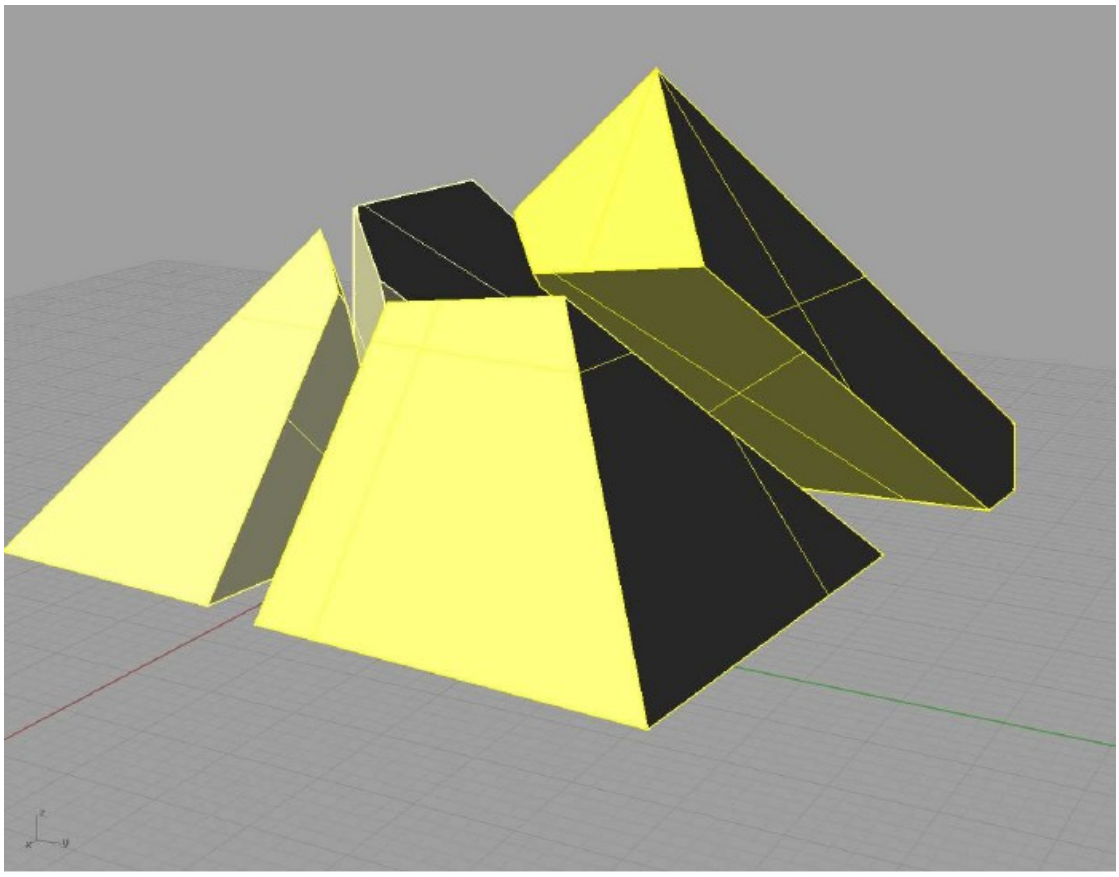

Figure 5 Form after voronoi script is applied

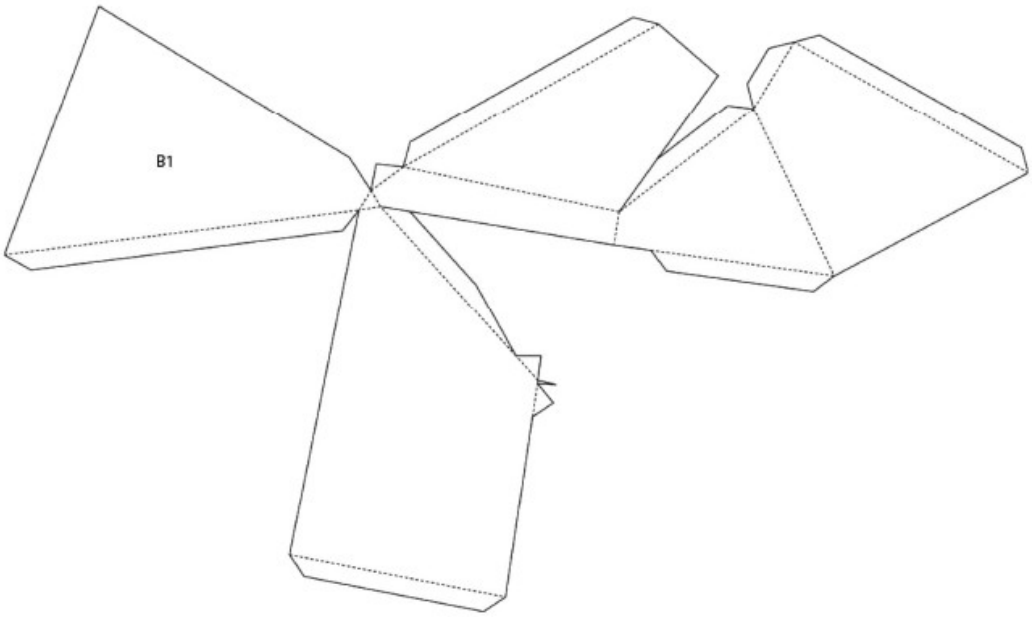

Figure 6 Form after it is has been processed and 'unfolded’

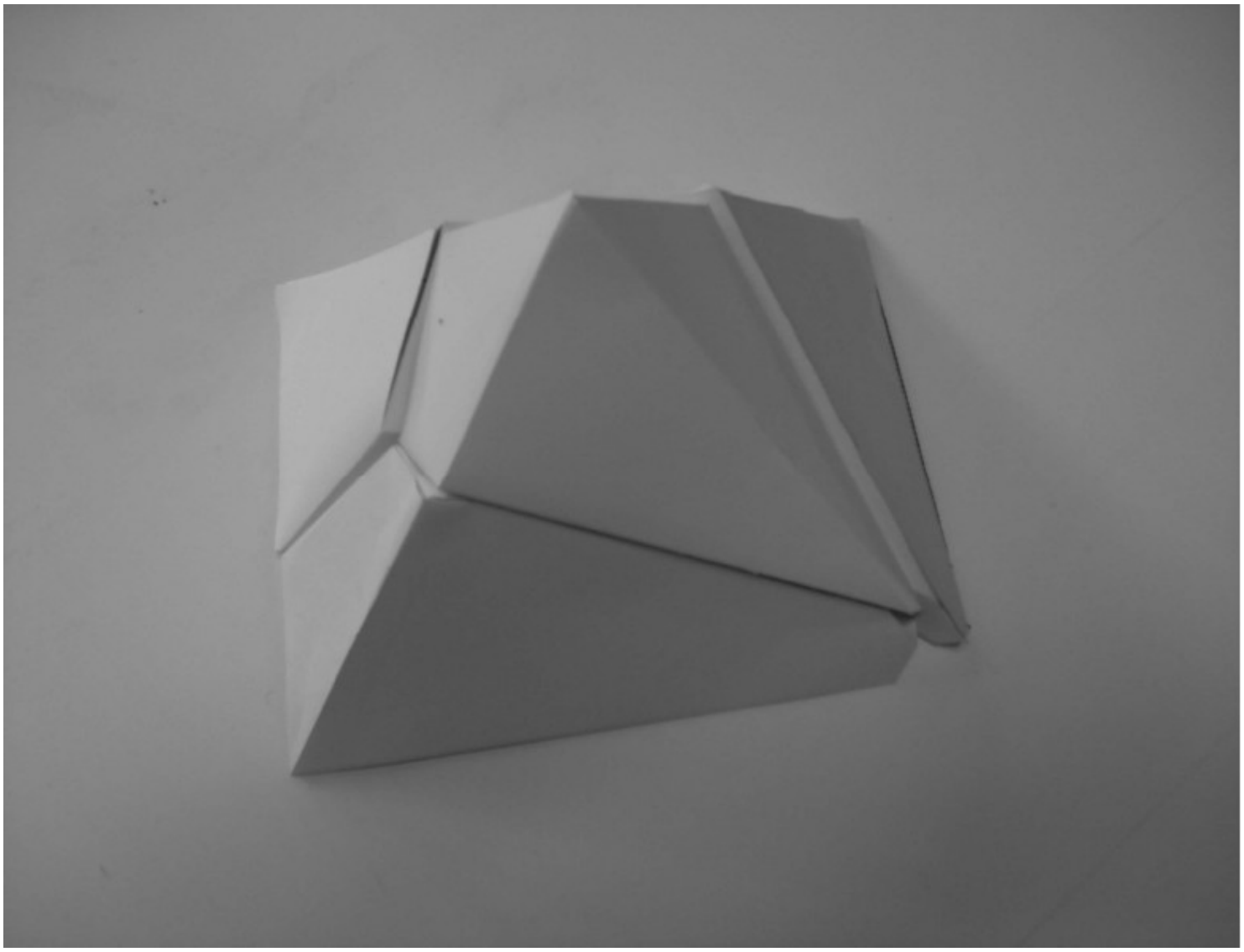

Figure 7 Form after it has been refolded

As software and hardware becomes increasingly accessible so too does manufacturing equipment. Kits can be purchased with the promise they can be do it *yourself* (DIY) assembled, which suggests that no particularly specialist knowledge is required for assembly. Which suggests such devices are within reach of the average individual, designer or architect. At least one DIY computer numerical control (CNC) router is available[48], as are several 3D printing kits[49]; making construction, development and fabrication of innovative design ideas easier and igniting a 'garage' culture of design and making within architecture. This continues to accelerate with cheap intuitive micro-controllers such as Arduino, open source communities generating considerable resources and global events like 'makerfaire,' which stimulate DIY innovation.

In the same way desktop CAD enabled small practices to compete with their much larger counterparts in the mid nineties (Coyne et al., 1996, p.125)[50]. Access to these DIY technologies is challenging the notion that cutting edge innovation only takes place in multi-national design practices such as Foster Associates, and is bringing design research

and innovation back to the individual designer/entrepreneur.

3. SUMMARY: SYSTEMISATION, TECHNOLOGY AND CRAFT

The aim of this paper is to increase our understanding of contemporary construction by viewing it through a historical lens. To do this we reviewed the legacy of a rule-based approach to construction and looked at recent initiatives that have promoted change in construction. The historical context of design and construction has promoted the development of rule-based systems for organisation and execution. Arguably, the very process of building and ordering the environment is a form of systemisation, so it is perhaps natural for this theme to dominate. Systemisation has been shown to be closely associated with notions of quality and within the construction sector technology has presented new opportunities for this. As we have explored the evolution of construction we have found rule-based systems appropriated as a means to assure quality throughout its history; from the ancient rules of Vitruvius through the pattern books of the eighteen and nineteenth century to current software systems. The more recent developments of the last hundred years see systemisation and standardisation continue to have a high profile in the development of the design and construction sector. Currently computing technologies such as BIMs provide the base upon which new methods of systemisation for the construction processes are being built, and MMC also continue to increase the rigidity in both the design and construction processes.

Unsurprisingly Vitruvius does not distinguish between the science of rule-based construction and the artistry of the process[51], as the artistic/scientific strands of design and construction only began to noticeably diverge after the Enlightment of the seventeenth and eighteenth century. The stonemasons and plasterers that we referred to, as well as reproducing also improvised and modified their patterns when circumstances demanded. Although the themes of systemisation and standardisation are clearly dominant within the historical and contemporary descriptions of construction, craft — albeit overshadowed — also runs through them.

The dominant contemporary description of construction is one where the artistry within the construction process is overshadowed by systemization. Construction is predominantly described in the functional terms of fabrication and assembly. This artistic aspect is absent from the current description of construction and although the notion of construction as *technê*[52] has been overshadowed by construction as technical, we claim that while artistic aspects of construction have been diminished within the dominant description of

contemporary construction they remain present and intrinsic to the process.

The contemporary description of construction has been revealed as one where functional aspects of fabrication, assembly and coordination dominate and the arcane aspects of artistry and creativity are marginalised. Technology features within this functional framework and the influence of technological interventions are considered in terms of their functional affordances. Little consideration is given to the influence exerted upon arcane relationships and other non-functional aspects of design and construction processes by the appropriation of new technologies. The construction sector envisions construction as logical linear processes of design followed by construction. It is believed that increasing the rigidity of these linear processes will increase the efficiency of the process. If we subscribe to the construction sectors logic then increasing systemisation will increase quality, and within this contemporary description computing technology is almost exclusively considered as a tool to increase rigidity and systemisation. Although mobile phones would seem to be an influential technology and widely used within construction, as this paper attests they do not feature as frequently as might be expected within the current literature. Even the modest design and construction project by Josh Stewart, Patrick Loo and Sebastian calls into question the effectiveness of current models for representing the relationship between participants, technology and design/construction processes. It adds currency to McCarthy and Wright's proposition that calls for richer models to understand human computer interaction[53].

Arguably it has always been a prerequisite that architect have a sensitivity to many disciplines in order to secure the construction of a building. An architect may not be fully skilled in joinery, quantity surveying, masonry or electrical and mechanical engineering; rather they have elementary knowledge of them all. However, increasingly this broad base of knowledge and skill is including computing and programming skills, which are not yet embraced as legitimate architectural constituents. Architects, such as Gehry and Eisenmann are occasionally cited as exemplars of the architect as designer of purist form, technicians and powerful technology leaves them removed from the 'hands-on' process of building construction. However, this model of designer would seem to be receding and the architect as hands-on hacker or '*homo universalis*' seems to be advancing. With skills in multiple domains architects continue to test oundaries and possibilities, using programming to inform the generation of form and using architectural ideas t drive new collaborations and forms of space.

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RORYRORY (2008) Gerritt Rietveld- Schroder House, 1923-24. Flickr.

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Notes

[1] According to McEwen there is evidence of another authoritative text from the sixth century. It is the Vitruvian text, owever, which has exerted more influence. For more on this see MCEWEN, I. (2003) *Vitruvius: writing the body of architecture, London, England, The MIT Press*. back to text

[2] For more on this see POLLIO, V. (1960) *The Ten Books of Architecture*, New York, Dover Publications, Inc. back to text

[3] For more on this see MCMORDIE, M. (1975) *Picturesque Pattern Books and Pre-Victorian Designer*. Architectural History, 18, 43-59 & 109-112. Also see RAWLINS, T. (1768) *Familiar architecture; consisting of original designs of houses for gentlemen and tradesmen, parsonages and summer retreats*. back to text

[4] CORBUSIER, L. (1987) *Vers une architecture*, Oxford, Architectural Press. back to text

[5] This position has been critiqued in detail by Pérez-Gómez. For more on this see PÉREZ-GÓMEZ, A. (1983) *Architecture and the Crisis of Modern Science*, Cambridge, MIT Press. back to text

[6] CORBUSIER, L. (1987) *Vers une architecture*, Oxford, Architectural Press. back text

[7] Early Modernist private houses in the UK started with such efforts as Le Château at Silver End by T.S. Tait (with Frederick MacManus) (1927-8). They were finished with render over a brick structure, trying to emulate the appearance of concrete. For more on this see FLETCHER, B. (1956) *A History of Architecture on the comparative method: for students, craftsmen & amateurs*, London, Batsford. back to text

[8] Broadbent has explored this criticism of inconsistency between form and meaning in greater depth, see BROADBENT, G. (1969) Meaning into Architecture. IN CHARLES, J. & BAIRD, G. (Eds.) *Meaning in Architecture*. London, Barrie and Rockcliff.back to text

[9] RORYRORY (2008) Gerritt Rietveld- Schroder House, 1923-24. Flickr. Use for academic purposes only. back to text

[10] Ruskin resisted and criticised industrialisation and standardisation and within the current context of this thesis his arguments have currency. However Ruskin's arguments are not without their critics, see GARRIGAN, K. O. (1973) *Ruskin on Architecture*, Wisconsin, The University of Wisconsin Press. back to text

[11] For current discourse on the influence of manufacturing and automotive production processes on construction see KOSKELA, L. & VRIJHOEF, R. (2007) Is the current theory of construction a hindrance to innovation. *Building and Research Information*, 29, 197-207. back to text

[12] For a more detailed review of prefabrication in the post-war period see BULLOCK, N. (2007) You assemble a Lorry, but you build a House: Noisy-le-Sec and the French Debate on Industrialised Building 1944-49. *Construction History*, 22, 75-95. back to text

[13] Three die as tower block collapses. BBC. "A public inquiry into the collapse in August 1968 concluded that a gas explosion had triggered the collapse of a building that was structurally unsound. It had been "system-built" using prefabricated concrete panels bolted together like a giant meccano set." Further critique of prefabrication in construction can be found in KOSKELA, L. & VRIJHOEF, R. (2007) Is the current theory of construction a hindrance to innovation. *Building and Research Information*, 29, 197-207. back to text

[14] (2007b) Nike to Cease Manufacturing Products. The Onion. back to text

[15] For manufacturing, China has become the country of choice for sub-contracting and the financial sector favours the Indian subcontinent. back to text

[16] Nike employs approximately 500,000, but only 22,658 directly at the time of writing. For more on this see LOCKE, R. M. & SITEMAN, A. J. The Promise and Perils of Globalization: The Case of Nike. back to text

[17] For more on this see MARX, K. (1977) Grundrisse. IN MCCLELLAN, D. (Ed.) *Karl Marx: Selected Writings*. Oxford, Oxford University Press. back to text

[18] The topping-off ceremony is not necessarily the completion of a construction project, when the Petronas Towers in Malaysia were topped off there was much work still to be completed inside. The topping off was more of a celebration of the completion of its appearance. back to text

[19] In 1983 the International Council for Research and Innovation in Building and Construction (CIB) was set up and initially focused on Computer Aided Design (CAD) systems, it has since widened its remit to include general Information Technology (IT). The European Commission also funded several initiatives focused on innovation using IT.

For more on this see BOWDEN, S., DORR, A., THROPE, T. & ANUMBA, C. (2006) Mobile ICT support for construction process improvement. *Automation in Construction*, 664-676. back to text

[20] COMIT (2003) Current Status of Mobile IT. back to text

[21] In 1993 the value of output from the construction industry was £62.8 billion and in 2006 it was £80 billion. For more statistics on construction output see POTTIER, F. & ACHUR, J. (2007) Construction Statistics Annual 2007. IN REFORM, D. F. B. E. R. (Ed.). London. back to text

[22] LATHAM, S. M. (1994) Constructing the team: final report. London, H.M.S.O. back to text

[23] Ibid. back to text

[24] Ibid. back to text

[25] Ibid. back to text

[26] For further discussion on the implementation of the Latham Report see HILL, C. (2001) Latham's legacy. *Building*. back to text

[27] EGAN, S. J. (1998) Rethinking Construction: The Report of the Construction Task Force. London, Department of Trade and Industry. back to text

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[31] For more on this see WEAVER, M. (2005) Government admits problems with PFI home repairs. *Guardian*. Harrogate. back to text

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[34] (2003) PFI Construction Performance. London, House of Commons Committee of Public Accounts. back to text

[35] Ibid. back to text

[36] WEAVER, M. (2005) Government admits problems with PFI home repairs. *Guardian*. Harrogate. back to text

[37] Report to the House of Commons states that a few years after completion, 20% of buildings put in a request to change the facilities. For more on this see (2003) PFI Construction Performance. London, House of Commons Committee of Public Accounts. back to text

[38] In the case of partnering a design solution may be passed from an original design professional to a construction organisation or their appointed design professional that then would modify it to be constructed cost effectively without the consent of the original designer. back to text

[39] For more on this see JONES, K. & KALUARACHCHI, Y. (2007) Operational factors affecting strategic partnering in UK social housing. *Engineering, Construction and Architectural Management*, 14, 334-345. Also see JONES, K. & YAMUNA, D. K. (2007) Monitoring of a strategic partnering process: the Amphion experience. *Construction Management and Economics*, 25, 1053-1061. back to text

[40] Design and build is not without its critics. The popular television program Grand Designs often illustrates design and build degenerating into perpetual changes resulting in long and frustrating building programs. back to text

[41] Within the current financial and environmental climate Tom Woolley continues to construct and report on the value of the design and build methodology. For more on this see WOOLLEY, T. (2006) *Natural building : a guide to materials and techniques*, Ramsbury, Crowood. back to text

[42] For more on this see (2007a) Design for Manufacturer Competition. English Partnerships. and (2008) Dwell Home Design Competition. archiCentral. back to text

[43] The HUF House system has been reported to being assembled and watertight in as little as seven days. See Huf Haus. Huf Haus. back to text

[44] For current discourse on the fragmentation of construction see KOSKELA, L. & VRIJHOEF, R. (2007) Is the current theory of construction a hindrance to innovation. *Building and Research Information*, 29, 197-207. Also see INGIRIGE, B. & SEXTON, M. (2007) Intranets in large construction organisations: exploring advancements, capabilities and barriers. *ITCon*. Also see PATHIRAGE, C. P., AMARATUNGA, D. G. & HAIGH, R. P. (2007) Tacit Knowledge and organisational performance: construction industry perspective. *Journal of Knowledge Management*, 11, 115-126. back to text

[45] YESSOS, C. (2006) The Singularity of Design Creativity. *eCAADe: Communicating*

Spaces. Volos, Greece, Xourafas. back to text

[46] Ibid. back to text

[47] SMEDRESMAN, G. (2007) 3D Voronoi Script. SEVENSIXFIVE. back to text

[48] METS, M. (2010) Portable wooden CNC machine. Make:. back to text

[49] ANDERSON, C. (2010) In the Next Industrial Revolution, Atoms Are the New Bits. WIRED. back to text

[50] COYNE, R., NEWTON, S., MCLAUGHLIN, S., JUMANI, A., SUDWEEKS, F. & HAYNES, D. (1996) Computers in Practice. Edinburgh, University of Edinburgh.back to text

[51] Pre-Enlightenment there is less distinction between art and science. The Latin *ars* is the word from which the modern term *art* is derived. Historically ars means art, skill and craft, the phrase does not distinguish between what we would now refer to as art and science. Also the phrase *poiesis* meaning creation, production and poetry blends together the notion of art and production. back to text

[52] Translated as either craft or art. PARRY, R. (2007) Episteme and Techne. Stanford Encyclopedia of Philosophy. back to text

[53] MCCARTHY, J. & WRIGHT, P. (2004) Technology as Experience, Cambridge, Massachusetts, MIT Press. back to text