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Chaszar, Andre

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Issues of Control and Command in Digital Design and Architectural Computation

Andre Chaszar

Technical University of Delft, Netherlands
O-Design Research and Consulting, USA

e-mail: a.t.chaszar@tudelft.nl

Abstract: Issues of control and command in architecture are considered here via reflections on recent and current research projects concerning digital technologies. The projects' topics cover a range of scales and approaches, from the planning and design of urban ensembles to the detailing of panels for constructing free-form building envelopes. Additional topics on this spectrum include methods to support open-ended design explorations, goal-driven optimisations, participatory design and the internet-of-things. In each of these the possibilities and methods for controlling the design process and the resulting artifacts and systems are addressed in different ways, which consequently influence the roles of architects in different ways. Overall we see that while digital technologies do indeed enhance architects' control in some cases, some applications require sharing of control with others, while still others may result in loss of control either to other parties - due to transferability of skills, for example - or altogether - due to complexity and feedbacks. Awareness of these different possbilities may aid better use of the technologies.

Keywords: design representation, procedural design, participatory design

Introduction

The introduction of digital technologies for design, analysis and construction of architectural projects has been proposed from the outset to offer architects greater control of their own work and of the other processes comprising the project. In many respects this has been realised, through enhanced capabilities for the production of representations (e.g. drawings, models, videos), data processing (simulations, quantity take-offs) and manufacturing and assembly (CNC cutting and milling, robotics, etc.) as well as communications and access to information [1]. Yet there remains room to question whether architects do now in fact have more control and greater command of their projects as a result. Also open to question are: who else might be gaining control and command, and whether such shifts in capabilities, responsibilities and power are helpful or harmful. This article suggests ways to address these three questions and related ones by examining issues of control and command arising in various areas of architectural research, especially ones concerned with utilising or creating digital technologies for various aspects of the design and construction process. While the examination is made with reference mainly to the author's recent and current research projects, its observations and conclusions can be interpreted more broadly and are also largely applicable to practice in AEC(O). The aim of this examination is, in part, to highlight areas where -- perhaps contrary to expectations -- control is not clearly maintained, in order to at least augment present awareness and diminish later disillusionment when the degree of command is not equal to expectations.

The present work considers the issues of control and command via reflections on research projects concerning digital design in architecture and urbanism. The projects' topics cover a range of scales and approaches, from the planning and design of urban ensembles to the detailing of panels for constructing free-form building envelopes. Additional topics on this spectrum include methods to support open-ended design explorations, goal-driven optimisations, participatory design and the internet-of-things. For examples of differing approaches: the research on urban planning and design utilises parametric modelling and embedded analyses to evaluate the anticipated performance impacts of alternative urban layouts and provisions of public space. The research on Custom Digital Workflows emphasises the need to allow for *ad hoc* linking of various software packages to enable flexible interoperability in multi-disciplinary design explorations, while the works on data visualisation tackle the challenges arising when making sense of results from large quantities of such explorations and optimisations. In each of these topics of research the possibilities and methods for controlling the design process and also the resulting artifacts (especially urban spaces, buildings and building components) are expressed in different ways, consequently influencing the roles of architects in different ways. The areas of research to be examined include ones in which the approaches and techniques applied result in situations where control is retained and/or augmented, where control is shared or delegated, and where control is lost or difficult to maintain. The three groups encompass (though not exhaustively) the following main topics:

1) design representation, analysis/simulation, optimisation, data visualisation, fabrication;

2) design space exploration, search and classification, urban prototyping, participatory design;

3) adaptive architecture, internet-of-things, 'smart cities'.

The demarcations are rarely firm, however, so the topics are intricately interrelated, and the degrees of control exhibited tend to form a gradated spectrum, as will become apparent. From the analysis following we can conclude that in general the digital design processes' levels of controllability by architects are inversely proportional to their level of complexity, and that the complexity can have various sources, as detailed further in the Discussion section.

Control retained or augmented

We can begin the exposition of our topics with that of design representation, where application of digital technologies was arguably first aimed [2] and has so far had greatest success. As a specific example, the long gestation and now maturing of BIM brings to architecture a system of representation which is standardised -- thus controlled, perhaps overly -- though this implies some loss, or delegation, of control, as discussed below [3]. Precision of representation is augmented, and arguably variety as well -- although this may be more a shifting of domain rather than actual expansion, as the varieties of analog representation are also enormous -- offering designers great control of how to express and develop their ideas, if they gain sufficient command of the media. Sharing and communication potentials are increased, giving control through wider and perhaps longer propagation of ideas through transmission and re-use [1,4]. Still, potential reductions in control stem from issues of system reliability, viruses, etc. (vs. physical damage to analog representations) and from questions about the applicability of approaches adopted from manufacturing when applied to more open design processes -- although these can be mitigated to some extent by recourse to more open design space exploration tools, ’custom digital workflows’, and approaches to interoperability [5,6,7,8] as discussed further below. Given these points, design representation with digital means on the whole seems to come out on the side of greater control, in balance.

The analysis and simulation (including virtual prototyping) of designs has also been an area where control is quite successfully established, with greater power and precision commonly offering greater confidence in the future performance of projected designs [1,4,9], as designs can be tested in greater numbers and greater depth. These tools can be used in the conventional mode of confirmatory analysis, but also provide useful input during earlier conceptual phases of design if handled properly, when relative merits rather than great precision are needed for decisions [10]. Tools for carrying these out are not always geared to non-experts, however, so their use may entail significant collaborative efforts [1,4,7] (see below) or else risk recourse to shaky assumptions giving results which can distort design decisions. Another associated risk is information overload, „losing sight of the forest for the trees”: a possible excess of choices and consequent disorientation in balancing conflicting requirements. These may be offset to an extent with good data querying and visualisation (see below)[5,8,9,10].

Optimisation builds upon analysis and simulation above, with additional power and control exercised through multiple iterations of goal-directed design revisions, greatly increasing the number of design variations examinable. Work on ‘custom digital workflows’ seeks to enable linking of possibly disparate software packages, giving more control over choice of software (for example those with which the design team is more familiar and confident) and over how design data are processed [6,7]. Yet not all aspects of optimisation remain firmly under the architects' control: for example the choices of optimisation algorithm types and their parameters, which often enough need expert input rather than acceptance of defaults. Large-scale optimisation also greatly increases the potential excess of data/information and choices (as in analysis and simulation above) unless brought under control, such as via good data interrogation capabilities [9].

Visualisation of data [9,11], coupled with sophisticated querying [5,6], offers potential to help reduce information overload and make the data from automated optimisation routines more digestible. The key is in enabling designers to find patterns in the data which after sufficient testing can be used as firm bases for design decision making [11]. Preferably the data visualisation tools also support interactivity, to let users control which data are examined and how, rather than providing only predefined views (though again, their use needs some expertise.)

Digital fabrication technologies have also been strongly heralded and then lauded for enabling greater freedom, complexity and precision of manufacturing for architectural projects (including physical models / maquettes) as well as reducing time, cost and waste. Such technologies may in cases allow experimentation through physical prototyping and consequent extension of previous boundaries to 'non-standard' designs and construction methods, testing limits of complexity [12]. Control of fabrication by designers can also help overcome difficulties of finding willing and able builders. There is, though, some danger of overextension beyond known performance limits without adequate prototyping (especially of factors not well handled by virtual prototyping), with consequent in-service failures at higher rates than with more well-established, reliable materials, manufacturing and assembly methods. If by excluding specialists there occurs a loss of deep, expert knowledge, the risk increases of producing 'expensive piles of junk', especially when realising projects in practice. Thus again, collaboration and the sharing or delegation of control may be needed.

Control shared or delegated

Design space exploration, as a paradigm related to but more general than optmisation, has also been aided in some respects by the introduction of digital methods for design generation and evaluation, through procedural modelling (such as parametric-associative geometric models) and computational analyses (such as performance simulations of structural, energy, lighting, thermal and other aspects). One of its most important distinctions from optimisation is that in exploration designers are not concerned only with finding the 'best solutions' to well-defined 'problems', but instead with producing and examining many, perhaps very widely differing, designs in a process where the questions to be answered and criteria to be fulfilled are still open [4,9,13]. This typically requires a less constrained and more interactive approach than optimisation, with potentially more collaboration, consequently more negotiation (therefore less command), and more interest in comprehending all of the (design) data produced in order to gain a better appreciation of the design situation and potentials.

Research on ’custom digital workflows’ [7,8] and ’multivariate interactive visualisation’ [9] address some of these issues by on the one hand enabling the construction of more open interative loops for design generation and evaluation, and on the other hand more effective comprehension of the copious data resulting from such processes. Designers can thus gain more control over the choice of software to use in design and analysis, and also more control in the face of information overload (noted above also as a potential problem with automated optimisation). The widespread use of digital models for design, analysis and other tasks, produced by different people using various software raises issues of data sharing such as the organisation and retrieval of data, as well as the transfer and translation of data [7]. While standardisation has often been proposed as the basis of the answer to all of these needs, practice has shown that standards are often observed only partially or not at all (as they do not sufficiently suit the localised needs of particular users and tasks), and standardisation is in any case not strongly supportive of creativity and innovation, which are often requisites in design. The ’custom digital workflows’ approach addresses this partially, as already noted, by aiding designers in assembling chains of software suited to their needs. However, further assistance is needed when creating the linkages, both in finding relevant data and in mapping those data to translate between packages. Control is thus potentially increased with data search and classification methods [5,6] helping users to customise retrieval and translation without recourse to standards, though at some cost of effort. But where standards are adopted for greater convenience, control is lost (or delegated), as ’universal’ conceptual schema for organising design information assert dominance and begin to condition how designers speak and think about their work, as well as how they must structure their design representations to make them shareable [3]. Another interesting approach to this issue of interoperability relies on algorithmic agents to negotiate ad hoc exchange protocols; in such a case the designer’s control is not lost to a universal standard but shared with or ceded to the agent(s) and those who programmed them.

’Urban prototyping’ applies digital design technologies at a scale of entire cities or districts, commonly using procedural systems (typically parametric-associative or other rule-based ones) to generate city models, and simulations and other analyses to subsequently evaluate and refine the designs produced. It shares with digital design and optimisation (see above) a potentially high level of control over the designs produced (barring much reliance on random or stochastic processes), and also potentially a higher degree of confidence in the eventual ’performance’ of the resulting urban fabric than would be expected from ’traditional’ (pre-digital) urban planning and design methods. Nonetheless, questions of control and command arise in at least two respects: first, the risks of overconfidence in analyses/simulations of very complex phenomena for which they are not really valid, and second, the nearly inevitable necessity of allowing urban plans and designs to mutate in the course of their gradual implementations, as more stakeholders are engaged, and as earlier requirements evolve or otherwise shift (such as with economic cycles, changes in governance, etc.). Thus, the appearance of control manifested so strongly during the analysis and design stages rarely translates through to the built city, even if some strong visual characteristics are retained. Digital technologies are of course also being strongly promoted for the operation (and adaptation, see below) of urban environments, as with 'smart cities'. The degree of command thereby is possibly very high, but it will likely be command by others, not designers. Nevertheless, digital technologies can contribute control to the processes of urban design representation, as noted above, and of sufficiently focused analyses, which need not be confined to purely technical performance but can also address matters of perception, such as assessment of 3D open urban spatial character via 'convex and solid voids' analysis [14,15]. Participatory design (collaborative and multi- or trans-disciplinary) is becoming increasingly prevalent in addressing urban issues, and while not in itself a digital technology, much digital technology is being put to service in realising it, to better marry design, analysis, communication and negotiation. Here the architect truly becomes one actor among many, though possibly with some prominence; command is out of the question, and control is exercised indirectly, if at all.

Control difficult or lost

The areas of 'adaptive' or 'responsive' architecture, while attracting increasing attention from architects, present significant challenges in control of design and analysis as well as operation. Taking as a premise that such architecture must dynamically reflect changes in its immediate physical environment, users' presence and wishes, and possibly also other factors, it commonly relies upon incorporation of control systems as part of the realisation (although some approaches instead achieve dynamic behaviour via material responses at cellular/molecular/atomic scales -- where the 'control system' is integral -- rather than through electromechanical means) [16]. Unless the desired responses and adaptations are trivially simple, maintaining command of the designed artifacts' behaviour(s) demands much greater effort from the designers, as well as knowledge which usually falls outside the domain of architecture (fitting more closely to electrical and mechanical engineering, among others). Of course, the designers may decide to let events take their course -- perhaps citing an interest in 'emergent behaviours' -- but this may be seen as tantamount to abdicating control. (See also Internet of Things, below.) In addition to the uncertainties of operation, design and analysis are also more challenging than with conventional (relatively) static architecture. This is partly due to effects of the necessary collaboration (see previous topics) and also because the number of possible states of the design is somewhat or even vastly greater. Having more states also means more evaluations are needed, if confidence in performance is to be maintained (and with so many evaluations needed, considering their computational costs, physical rather than virtual/digital prototyping again becomes attractive). Thus, even a single artifact with one or a few defined behaviours is difficult to really control from design through operation -- and as in software design „if you can't fix it, feature it" may become the motto. This is compounded, of course, when more objects, users and behaviours are in play, such as in urban assemblages and the 'internet-of-things'.

Whereas adaptive and responsive architecture typically deal with a single artifact or a collection of its similar components, the Internet-of-Things is about a much larger ecosystem of devices, in which architectural artifacts can also be included. Thus, the challenges of control noted above are greatly compounded by the greater number of devices, users, behaviours and interactions possible. Within such a milieu, the architect can at best hope to define an 'envelope' of possible outcomes, based on what can only be approximate assumptions about the possible inputs. Failure to take into account what the artifact may encounter and what its responses might be can of course lead to failure of the artifact, or in better cases a kind of graceful degradation of performance (perhaps simply non-response, keeping to the previous state, or reverting to a 'neutral' state), or maybe in the luckiest circumstances a new kind of behaviour which was unanticipated. Here again claims of control are tenuous, unless live, on-the-fly reprogramming (in effect remote control) can be implemented.

The move toward Smart Cities represents a sort of apotheosis of the intersection between architecture and the Internet of Things, although with many buildings remaining relatively static artifacts, having their responsiveness confined to the already well-known realm of building control systems for lighting, HVAC, security and so on. The sensor and actuation networks being designed and put in place to collect data on these systems as well as a host of infrastructural and other non-architectural artifacts, and to control their behaviour -- in ways aiming, it is said, to optimise their performance and efficiency -- could in principle accommodate more ambitiously responsive and adaptive architecture as well. But smart city systems are not being designed or implemented with much or any input from architects, so it remains to be seen whether and how much control or command they could exert through them. The complexity even of comprehensively sensed cities remains.

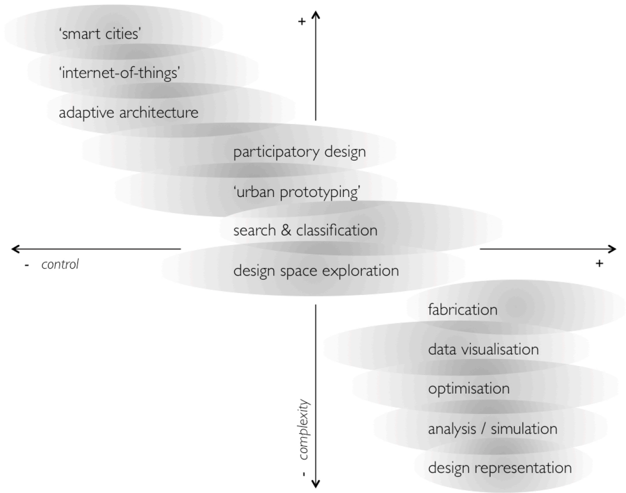

Figure 1: schematic summarising relation of complexity to control.

Discussion / Conclusions

The preceding reflections on recent and currently ongoing research have provided an instrument for examining how control is gained, shared or lost by architects in the course of applying digital technologies. Roughly speaking the degree of control correlates to the complexity present, as shown schematically in Figure 1. Situations or processes with one or few actors and simple cause-effect chains are those in which control is most easily maintained, where command can effectively be exercised. Contrastingly, those with multiple (even multitudes of) actors and complex processes -- whether through feedback loops or other inherent sources of complexity -- are those least controllable, where the idea of command is illusory.

Another source of potential loss of control is the transmission and fungibility of skills/knowledge and the resulting interchangeability of roles. With digital technologies for architectural application, it is clear that not only architects can utilise them, and the domain knowledge encapsulated in them may actually give a leg up to non-experts. Competition (from non-architects) is now consequently greater than before. Other effects include clients' expecting that design changes can be more numerous and frequent, due to perceptions that digital tools make changes easier. Thus, control of project schedules, workloads and profitability comes under pressure. This is not to say that these must be avoided. Often sharing or abdication of control is desirable or necessary (e.g. participatory design), and this recognition is growing in some circles of design and beyond -- although also shrinking in others. The choice of how much control or command to attempt to exert is partly a matter of pragmatics, partly of ideals; ultimately it is political.

This work has aimed to examine more closely whether and how digital technologies augment or reduce architects' control, and we can conclude from observing the variety of results in various areas of such technologies' use that care should be exercised in selecting which technologies to use, and in forming expectations about the resulting degree of control and command. The surest way to maintain command may seem to be to restrict architects' activities to well-understood and relatively tightly constrained tasks, though competition from others (non-architects) with comparable or greater skills can still displace them. For those choosing more dynamic definitions of architects' roles and possibilities the challenges are formidable but may be successfully attempted with „eyes wide open". It is hoped the analysis presented here contributes to such opening; the synthesis into action remains with the readers.

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