

# Connecting Parts to Wholes in Construction Education and Practice.

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Construction education is traditionally taught through explaining the parts moving from simple to complex elements. The main subjects taught are technological, thus encouraging, all issues to be considered in this reductive manner. This paper considers the implications of this and presents systems theory as an approach which helps construction students to connect the parts to the whole, in particular, incorporating technology into a wider social perception which is required for sustainable construction. Systems theory has been used in construction research for over 50 years but this has had little impact on construction education. Systems thinking involves seeing the way parts are connected together whether physical entities or social organisations resulting in the classic expression that the whole is greater than the sum of the parts. The most common view of systems is as machines, however this is merely one category of system (designed physical system) and it is the others (designed abstract system and human activity system) which provide more insight into the operation of complex activities such as construction. It is the integrative, interdependent and complex nature of real world situations which can be represented by systems. The concept of complexity not only describes something with a large quantity of parts but involves not knowing what all the parts are and how they operate together even though the whole has perceived existence. Thus, the subject of systems is about a way of thinking through these problems and finding ways of representing them. The approach to this one semester course is outlined and examples of students work discussed in order to show the value of this for connecting parts and wholes. The paper also explores the utility of the tools for practice.

**Keywords:** systems thinking, rich pictures, sustainability

## Introduction

Construction education was not formalised until the middle of the 20th century (Langford and Hughes, 2008). Before that it was undertaken through an apprenticeship where learning took place by watching and being told what to do by someone with experience. This successfully transferred craft skills and to some extent the managerial aspects (although these were probably not referred to as such) were also passed on in a similar way. The fact that this had worked for millennia has meant that it is embedded in our social structures and this is evident throughout the world. However, construction and its organisation became more complex with the creation of larger structures, with the inclusion of more functions in use and with new technological methods of construction. In this complexity, the need for conceptualising the end product in a lot of detail became essential as did conceptualising the means of putting it together. This conceptualisation helped create the end building as a working whole but also in communicating this to the many parties that were involved in the building of it. The advent of ICT in the design of buildings has again created a need for changed conceptions.

The science of building took over from the apprenticeship transfer arrangement. Aspects of structures, of materials, of flows, were studied in detail since the late 18<sup>th</sup> century to reveal their essence so that an improved and more efficient building process and operation could be affected (Langford and Hughes, 2008; Wells, 2010). Much of the earliest research work was merely undertaken by observation and recording such that a greater understanding of the practicalities of construction could be generally known. A more abstract understanding, with these observations being incorporated into mathematical formulae, allowed a promotion of theoretically derived improvements. This was particularly successful in structural design and this also drove the development of new materials such as steel frames and reinforced concrete (Kurrer, 2008). This precognition of the operation of building elements allowed a much tighter use of materials and a much more accurate construction that accompanied developments in engineering and manufacturing. The success of this provided a further concentration on studying the parts of the building and a specialisation of skills both in design and construction. However, this specialisation caused fragmentation of the building design and construction process and a separation of concepts from actions (Boyd and Wild, 1994). The science of building still dominates construction education (Franklin, 1992; Boyd and Pierce, 2001; Ashworth, 2008). This is necessary to ensure accuracy and efficiency in technical construction. However, this science view is used beyond technology to building economics, project planning, law and even management where e.g. the parts of the subject are studied such as elemental costs, activity times, contract clauses and motivation. Technology of construction is also often taught through a defects perspective thus students pick up the idea that they are avoiding problems rather than creating workable wholes. This leaves out some conception of the whole with it being assumed that the sum of the parts makes the whole. The risk is that no whole is created or a single error invalidates the whole.

This paper explores this problem of a lack of connection between the technical parts view and the whole purposeful view of the client and surrounding stakeholders. It will explain the failure of the parts view and introduce systems thinking as a way of maintaining the benefits of this view whilst acknowledging the fundamental importance of the whole conception of building. It will detail some studies

already undertaken using systems thinking in construction and then relate how this can be learned in construction education. Examples from students work are analysed to show the development of thinking and it is then argued that this is a useful skill in practice.

### **The Failure of Lack of Wholes**

Construction has relied on architecture to give it a strong concept of the whole, so that construction itself struggles to see the whole (Allinson, 1995). Maybe the sequence of construction starting from small material entities encourages a belief in the creation of wholes from parts (e.g. Emmitt and Gorse, 2010). The failure is that, in both the conception and the reality, decisions are made in this compositional manner rather than with a strong awareness of purpose, context, and the way all elements work together. This creates a situation where it is known how parts connect to immediate parts but there is an ignorance of the way parts accrue into a greater operational entity. During the design, both in architectural (Perez-Gomez and Pelletier, 2000) and engineering terms (Kurrer, 2008), the whole is represented by schematics in the form of drawings. Drawings provide an attempt at connecting building parts to a whole building but this whole excludes the purpose and often the construction (Perez-Gomez and Pelletier, 2000). Drawings do not represent the actual building but an abstract conception of it. For many centuries, this abstraction was two dimensional with very limited connection with the whole thus became very inadequate in complex arrangements. Indeed although the basic form of the ground plan can be contained and represented; how the building works in relation to the ground and how it will be experienced in approach is absent. These may appear unimportant to construction which might be limited to whether it stands up but construction provides the quality both of the finished product and the satisfaction and acceptability of the means of production. Indeed many of the innovations in construction management such as lean (Koskela et al., 2002) and BIM (Hardin, 2009) are driven by a desire to work with a greater connected whole and use this to get buildings to work more effectively and building itself to be conducted more fluidly and accurately. However, both have a problem of being reductive views, starting with parts and adding more parts, without engaging the problem of integration and operation.

This problem will become more severe as we address the different challenges of sustainability which add more dimensions to the building problem and we are faced with more complex problems that cannot be addressed by parts alone (Hannigan, 2006). We need to see the way technological interventions are not just possible solutions but also may be part of the problem. We need to see the way we can get more out of artefacts having multiple purposes and meeting multiple criteria. We need to see the way technologies work with people and organisations. This is not just efficient (a concept of scientific parts) but is more socially meaningful and acceptable and also effective in the long term. We must not solve one problem and create others; we must solve the metaproblem (Flood and Carson 1993). We are not solving the short term at the expense of the long term requiring a concept that works with the dynamic of the entity in the world. We need to connect much wider issues to the locus of construction and so address how we can make decisions across different domains and different time horizons. Every action has to be considered against the triple bottom line: social, economic and environmental (Sodagar and Fieldson 2008), thus, we need to connect these high level aspirations to the low level actions. Construction then is not just about delivery in the instant but about building existence over a life cycle.

### **Systems Thinking**

The stated purpose of systems thinking is one of integration and it is part of its conception to see the whole as greater than the sum of the parts. Von Bertalanffy (1950) is credited with making the first articulation of systems theory. However, the elements for it had been in existence for the previous century combining the fields of sociology, ecology and engineering (Carter et al., 1994). Science had been extremely successful in developing causative explanation which allowed local control of entities but somehow the reductionism limited its application (Checkland, 1981, Rosenhead, 2001). What Von Bertalanffy (1950) saw was that our thinking and action required a new approach; indeed that there was a general approach to conceiving the world where everything was connected together and in particular the notion of feedback meant that the consequences of intervention or change were not simple. The ecological view began to see nature as something that operated as a whole so that removing one aspect affected the whole. The engineering of large systems like railway networks, power stations and chemical plant seemed to give the belief that it was possible to control complexity with greater knowledge, however feedback from those working in these fields revealed that although they could get them to work, the understanding of why they worked was limited (Stacey, 1996). Maybe the epitome was the space programme where large and complex organisations produced large and complex technology in a physical situation that was outside experience. The Challenger Disaster in 1986 then became a defining failure of belief in the omnipotence of space technology (Vaughan, 1997). Finally the idea of society and social organisation seemed to require a more considered approach. Strategy and policy had relied on quite simple thinking and objectives. As governments believed that they could change society then so their intervention became more challenging. The failure of many social programmes suggested that social understanding was limited (Forrester, 1971).

The most common view of systems is as machines, however this is merely one category of system (designed physical system) and it is the others (designed abstract system and human activity system) (Checkland, 1984) which provide more insight into the operation of complex activities such as construction. It is the integrative interdependent and complex nature of real world situations which can be represented by systems. The idea of general systems thinking is that the ideas are applicable to any field: ecology, motor engines, contract law or social housing provision (Carter et al., 1994). This allows us to learn more effectively from different fields but also to have a skill in interrogating unfamiliar fields i.e. handling incomplete knowledge in one field through learning from more complete

knowledge in another field. The important aspect is that it is about learning not merely about adopting the simple analogous knowledge for example not controlling an organisation as if it were a machine but learning how feedback and interaction can help us find appropriate points to influence the organisation. A second idea of general systems thinking is that the ideas are applicable to different scales: hydrological capture, water supply network, local utility infrastructure, building water pipework. Again, it is about how we can learn from one level to another rather than simple analogous replication.

There are a number of different positions on systems thinking that emphasise different aspects although they all try to deal with the inter-connected complexity of the world. These can be distinguished by being either hard or soft systems. The first being approaches to the world which display fixed and agreed viewpoints emphasising causation and a degree of predictable certainty including such areas as systems engineering (Weiner, 1945) and systems analysis (Simon, 1969). The second acknowledges the socially constructed nature of our human organised world such that there are multiple viewpoints and mutual causation; this is most comprehensively articulated by Checkland's (1981) soft systems methodology. There were various offshoots, for example systems dynamics (Forrester, 1971) which used a more mechanistic viewpoint to model complex human phenomena.

A system then is a collection of parts related together that has a meaning as a whole separate from its environment. The idea that there is a thing of interest provides us with a social meaning. The development of system theory emphasises the inter-connectedness of activities. In particular, it appreciates how causation is not simple and change feeds-back on itself through a series of linking changes. These multiple feedback loops interact and represent how change and intervention involve complexity such that outcomes may be counter-intuitive (Forrester, 1971)

### **Systems Thinking in Construction**

System thinking allows us to comprehend and then represent the complexity of construction and the construction industry and, in particular, it can help us to understand the connection between the parts and the whole. Most construction projects cannot be isolated to a technical problem of material construction. Projects are replete with interactions from the fragmentation of the construction organisation, the separation and fragmentation of the design organisation, the impact of the surrounding influences such as client decision making, financial environment, the development planning system, the political situation, the labour market and the local neighbourhood of the site. The latter only identify some of the surrounding influences and it is establishing what these might be and indeed their form of influence that provides some practical application of these ideas. Construction then is not merely the mechanistic performance of pre-conceived technical and social design/plan but the management of the interaction of these designs/plans with the complex world that constitutes the construction systems and surrounds it in its environment. These skills, once learnt, become tools for use in any other complex human technological interactive situation allowing construction people to have many different directions to travel in their careers.

In fact, some early work in socio-technical systems investigated the construction industry (Crichton 1965). This established the complexity of construction and where its systemic failure lay. At a more academic level, Walker (1984) used systems thinking to present the operation of the industry again from a management perspective. Stewart and Fortune (1994) used a systems approach to investigate risk aspects of the wider Humber bridge project in the UK. Recently, Blockley and Godfrey (2000) have conceived a most comprehensive system's representation for construction enabling an understanding and control of technical and social feedback. In a more radical way, construction has been presented as a loosely coupled system (Dubois and Gadde 2002) and systems theory has been used as a representation of case studies (Sustrina and Barrett 2007).

### **Systems Education**

Although there is a practical skill involved in presenting systems diagrams, the real expertise lies in thinking through and around a situation of interest. The difficulty for education is teaching something which cannot be taught and assessing something without a definitive output. The creation of the diagram is a tool for doing this. The subject of systems is about a way of thinking rather than the thoughts themselves thus the task is to assist students in developing a different conceptual model of the world. This is challenging because students wish to have instant solutions to set problems; there is a difficulty in changing conceptual models as the old model always appears more attractive because you understand it and the utility of the changed thinking is not immediately apparent. It is extremely difficult to change the way people think. In many ways it is no use telling them what they should do, what is required is getting them to think and reflect on how this is taking place. Thus, systems education requires a short descriptive and definitional introduction; firstly presenting systems descriptions of construction situations, showing the depth of awareness represented in these, defining the terms of systems and showing how the systems representations can be used to re-view the situation. Once this is undertaken then students must engage themselves with systems thinking. These ideas are delivered in a one semester course involving twelve 3 hours sessions which are run as workshops as much as lectures.

An early concept to explore is the nature of hard and soft systems (Checkland, 1981). This exploration can be induced by asking students to place a meaningful boundary in a system. System boundaries appear undisputed until real dilemmas of inclusion have to be addressed (Carter et al., 1994). For example: is the client part of the construction system? or is the outsourced security team part of the

construction system? Regarding the former, although the client may not be responsible for delivering to the work plan, they are certainly part of the on-going decision making on many projects. Excluding them assumes that they are independent and must be treated as a random environmental feature. This may be acceptable for distant clients and simple buildings but in specialist buildings (e.g. hospitals) it prevents good decision management. Regarding the latter example, outsourcing is undertaken to remove day to day management and reduce overheads; however, again an ineffective and unresponsive security team can result in delays thus suggesting placing them in the construction system. What can also be asked from these examples are questions of control. The fact that there may be management authority over some parties but not for others can be identified; in the case of the client their authority may be against project management. These examples are at a greater project level; however, the same conceptualisation can be undertaken within a project. For example, consider the fitting out of a room in a building; there are many players involved: tilers, second fix electrics, and painters. However, the room may be part of a wider system; for example, it is a route to another room or it is used by another workperson during their break thus the other room or other work-party is in the room finishing system; or another example, that the tilers and painters fell out on the last job and are bent on revenge, thus the other job is in the room finishing system.

The second concept is one of representation of systems. As has been mentioned, diagrams are an important part of systems thinking. Other representations include: the brief, written specifications, structural calculations, financial budgets, project strategy, work plans, perspectives, photomontage images and physical scale models. These all have the same character, in the sense that they represent what is conceived in an abstract manner. It is important for students to realise that they are not the real world but representations of this. They are therefore a reduction and are limited. It is this limit which needs to be explored. We have been seduced into believing that calculations and mathematics are the way the world works and so are true and complete. Indeed artificial intelligence suggests that we can substitute these calculations for managing events; however, the warning of their limitations must be recognised by professionals (Dreyfus and Dreyfus, 1986).

Systems thinking uses the representational mode of diagrams as a tool for thinking and communicating (ICRA, 2010). We consider three diagrammatic forms: rich pictures, influence diagrams and hard systems diagrams. Students need to learn to produce these and then be able to critically evaluate them. Neither is an easy task and skills need to be developed progressively. Rich pictures provide a way of representing the complexity of the situation (e.g. figures 1 and 2) (Checkland, 1981; Stewart and Fortune, 1995). They are soft in the sense that they are from a particular perspective and other participants in the project would identify different pictures. Just realising that this is the case is an important piece of learning for students so that they do not assume that their view, or their organisation's view, is absolutely correct. Indeed this can be used as a management approach when rich pictures are created by different actors in a project then in a group session shared so that differences are surfaced.

In many ways, hard systems diagrams are a complete contrast to rich pictures which acknowledge disputed viewpoints. The normal construction representations such as construction drawings, process charts, organisational charts, Gantt charts are taken to be hard systems diagrams. This is a character of how they are looked at rather than what they are. It is assumed that hard system diagrams have an agreed interpretation across different actors, assuming the actors know how to interpret them in the first place (Checkland, 1984). This does not mean that they cannot be misinterpreted or indeed selectively interpreted as they cannot show everything nor can they contain their own interpretation; i.e. they are not un-indexical (Clegg, 1992). The systems view of hard systems is that they are an important fixing intervention in the overall human activity system. They are required to achieve group coordination in activities but they are not neutral.

The third system concept of importance is the connections between entities whether they are human or physical. This also relates to the third diagrammatic form that of the influence diagram, although connections are also placed in the rich picture. The influence diagram is a more formal stakeholder type analysis but which can identify communications, power and impact. These connections respond well to being seen as influences and can be represented in influence diagrams. Each stakeholder has a set of values which they use to communicate and act with other stakeholders (Rokeach, 1973). Students benefit from understanding how human values are constituted, maintained and changed and how value-conflicts impact on human interactions. There are two sets of values those that are tangible and those that are intangible (Samad and Macmillan, 2005). The hard system is good at representing and even calculating tangible assets and drivers; however, much of constructions' value is intangible and more qualitative and experiential values are required to be invoked. This system of connections allows other theory to be introduced and students are encouraged to use theory delivered on other courses. This they find satisfying as it integrates their programme and connects parts to the whole. The case study basis of this education also connects the theory to practice, much needed aspect of construction courses to overcome criticism from students and employers; but also it provides a deep analytical understanding and skill which can be useful for higher level work such as dissertations and even PhDs.

### **Examples of Students Work**

The use of systems diagrams for studying complex construction is something that has to be learned and developed. Two examples of student work are shown in figures 1 and 2. The first is a rather simplistic and unthoughtful representation of a refurbishment of a city centre office block. The student has presented the stakeholders almost as a list each with a single connection to the development. There is value in this as it provides a greater appreciation of the influences that direct the actual project. However, it suggests that each

of the influences acts independently and has no incorporation of the form of the influences. Figure 2 is a much stronger example showing an extended appreciation of the influences on a project. This is a more complex situation as it is a hospital extension. What can be seen is the way there are numerous external influences affecting day to day operations. It is multi-disciplinary and multi-mode; e.g. the technical problem of site delivery interacts with the clients business (visitor parking), noise issues with patients as well as operational issues on site. Such interdependent problems are common place on sites and it is systems thinking's ability to identify such issues that provides both an educational exercise and a strategic management tool. In effect, identifying potential issues allows effective operational management. This is enhanced by the influence diagram in figure 3 where the problem of reciprocally interdependent communications (Thomson, 1967) is evident identifying the problem of communications and site operations.

The hard system diagrams such as process diagrams and Gantt charts are not sufficient to manage a project as a whole but a necessary tool of management. Getting the students to understanding this gives such diagrams more meaning and, importantly, acceptability. It is often found that busy site staff do not or cannot work through the formal system but create the documentation after the event as if they had used them and so avoid the value of formal and see it as a burden. However, by placing them alongside the soft system rich picture and influence diagrams, it is more evident why the formal is needed. Indeed the formal hard plan can be placed as an agent in the rich picture where it represents an influence on the other agents. Also the question can be asked 'which parts of the formal are just a paper exercise and not adding value to the end product' and 'which parts need to be enhanced to be stronger to overcome communications barriers across complex and conflict ridden inter-organisational boundaries'.

The tool is also an analytical tool in the sense that it can be brought to bear on a project case study as if the student was a researcher (e.g. Crawford and Pollack, 2004). In fact, a very sophisticated example of this is provided by Sutrisna and Barrett, (2007) where not only the structural features of the project are displayed but the developing progress of the project can be represented. The skills and time necessary for the latter may be beyond students but they can at least see that such an approach could be developed more formally as a progress monitoring tool by organisations. Proust et al. (2007) have used systems thinking and diagrams as a stakeholder management tool in complex environmental decisions by getting groups to present their perspectives, share these in a consistent way and then to work on creating a perspective which can be used to move the complex problem on.

## Conclusion

The paper has highlighted the need to connect the parts to the whole in construction education and practice. There has been a tendency to concentrate on the parts because of construction education's technical heritage. However, this produces a necessary but limited view thus creating problems in management. The use of systems thinking as a tool to connect parts and wholes has been demonstrated to be effective in construction education enabling students to appreciate where parts fit in and where problems arise from interactions. It is suggested that systems thinking could be a tool for construction management once these students become senior in practice both for analysis of the situation and also for sharing different perspectives of the situation. Such a skill is required for the more complex nature of sustainable construction which involves multiple perspectives of the future and conflicting approaches to implementation. and was the basis of early seminal work (e.g. Meadows et al., 1971).

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