PERCEPTION "NOISE" IN THE COGNITION OF VISUALISED CONSTRUCTION PROCESS CONCEPTS

SUBMITTED: December 2001
REVISED: July 2002.
PUBLISHED: August 2002 at http://www.itcon.org/2002/10
EDITOR: Abdul Samad Kazi

David R Moore, Dr
Manchester Centre For Civil And Construction Engineering, UMIST
email: david.r.moore@umist.ac.uk

SUMMARY: *Within the context of a scoping study the paper examines factors having a possible effect on the nature of cognition achieved with regard to specific construction industry production process concepts. These factors are considered with regard to the level of cognition, as a follow-on from the act of visual perception, that may be achieved by individuals with regard to production process concepts. The key production concepts considered are those of the extent of continuous specific interdependency (CSI) and discontinuous specific interdependency (DSI), as determined through assessing type and extent of discontinuities between construction activities linked by the process logic to form process chains. Existing means of visualising dependencies within and between projects are argued to be deficient with regard to their ability to communicate relationships such as discontinuous specific interdependency. Existing HCIs, for example, are suggested as simply seeking to replicate means of visualisation that are historically established, such as the bar chart, CPN, PERT, etc. This approach is considered within the paper from the perspective of the suggested differing abilities of experts and novices to "fill-in" the gaps presented in the context of communicating relationships such as DSI. The use of a structured entity approach to enhance the communication of concepts such as interdependency through the visualisation of relevant characteristics of individual activities is proposed. This entity is developed from work carried out in areas of research such as thinking with diagrams (TWD), knowledge maps, and the theories of perception with regard to pattern recognition. The suggested entity also seeks to maximise the value of current HCIs rather than imposing a radically new means of visualisation on project planning software.*

KEYWORDS: *Perception, near-criticality, interdependency, visualisation, TWD, structured entities.*

1. INTRODUCTION

The paper considers theories concerning: the act of cognition within the general context of construction industry production processes; visual perception and how this may be linked to information visualisation, and "noise" in visual communication of the production process concept of interdependency. Specific meanings for certain terms are adopted. These are included in a glossary at the end of the paper.

Two important abilities for planners and managers of construction production processes are recognising the existence of interdependency between two or more production activities/events, and determining the extent and nature of that interdependence within a project as a whole. Such abilities are both implied (generally through discussion of interdependency's close relative; dependency) within the literature concerning construction project and production planning (Walker, 1996) and identified explicitly (Moore, 2001). Basic interdependence can be identified relatively easily; if an activity adds nothing to the completion of a given project, it represents a waste of resources and should be removed as no other activity is dependent upon its completion. This approach to identifying basic interdependence can be found in long established systems models such as ICE (import, conversion, export) as suggested by Miller and Rice (1967) and is relatively simple. This paper, however, proposes the formalisation of a more complex form of interdependence that may be referred to as specific interdependence (see glossary of terms). The specific form is suggested as involving the issue of those activities that lie on a direct path of precedence forming process chains both within and between projects, and being a particularly difficult form to visualise for those without the required level of supporting expertise in planning. Nonetheless, it is a form that is important to the operation of planning techniques such as critical path analysis (CPA), albeit without being made fully explicit within the guidance concerning the application of such techniques. Moreover, it can be argued that of greater importance in managing production processes is whether specific interdependence exhibits characteristics identifying it as a continuous or discontinuous form. The continuous form can be established where there is little or no evidence of significant (determined usually on the basis of expertise and the culture of individual project organisations) discontinuities with regard to the 3 t's of time, territory or technology (Miller and Rice, 1967) between interdependent activities. Conversely, the discontinuous form is argued to exist where there is evidence of significant discontinuities regarding the 3 t's. Discontinuous specific interdependence (DSI) is argued to be the potentially greater problem of the two forms with regard to managing production processes because of its repercussions for the fragmentation of resourcesin terms of interface management.

The issue of DSI is not well handled by critical path network (CPN) and PERT charts, as they tend to regard activities as simply being either 'critical' or 'noncritical'. The closest concept to DSI within CPN/PERT terms is suggested to be that of near-critical activities. However, even this concept is not clearly communicated within present forms of visualisation, and is dependent upon the viewer being able to make judgements regarding criticality on the basis of how much float is "safe" for a particular activity on the basis of their perception of that activity's importance to the overall programme for one or more projects. On large and/or multiple interdependent projects, the visual array presented may take considerable expertise to decode. Indeed, it is possible to argue that the present forms of visualisation for critical activities in CPNs detract from the effective communication of the specific interdependence concept. The much simpler Gantt chart, for example, is certainly seen to have advantages in this respect (Field and Keller, 1998).In order to identify specific interdependence effectively there is a need to know what activities are required within identified process chains, the logic of the order(s) in which they can be carried out (precedence), and the type, quality and quantity of resources required. Satisfactory completion of this process demands a certain level of expertise. Experienced managers are generally deemed to have sufficient expertise (although there is a danger in assuming experience to equate directly with expertise) to impose the required understanding on what a production chart (CPN/PERT, etc.) may appear to be communicating. Such an approach has to accept, implicitly or otherwise, that when this understanding is represented by project planning software it tends to be in terms of events and activities that are relevant to the project as a whole. These are simply visualised by project planning software as being critical, near-critical or non-critical. The identification and handling of specific interdependent activities in particular is left to the expertise of the user in that expertise can be applied within the visualisation environment, but without the assistance of the HCI. In essence the final cognition of DSI, for example, depends upon incompletely visualised relationships being perceived by the expert and then processed further to form a more complete mental map of the project. The mental map concept is suggested as being an important one in that human cognition appears to be achievable on the basis of three-dimensional processing; it is possible to envisage process chains and/or projects unfolding in three dimensions (such as in the case of multiple concurrent projects). The ability to do this is a feature of the thinking-with-diagrams approach discussed in a later section of the paper. However, current HCIs within the context of project planning software are essentially two-dimensional and are therefore limited in their ability to assist the user in developing such ability. This situation is changing in areas outside of project planning, with a particular example being the use of knowledge maps within the field of knowledge management. The essence of the knowledge map approach is that individuals (in this case members of the project team) will only act with regard to issues that they understand and accept (Applied Learning Labs, 2002). The knowledge map approach seeks to turn individuals into knowledge partners through providing a supportive environment in which they are required to use their minds to form the map into a mental model of the issue being addressed. This mental map allows them to reach their own conclusions, rather than having conclusions imposed upon them by a presentational form that they may not fully engage with (such as PERT charts, etc.). The issue of knowledge maps in particular (and knowledge management in general) has a relevance to the concept of structured entities within the research area known as thinking with diagrams (TWD). TWD will be discussed further later in the paper. However, accepting that information relevant to relationships such as CSI and DSI, particularly perhaps with regard to the development by novices of expertise (through the management of knowledge), is of benefit to the user of the software, the problem for the software designer becomes one of how best (with regard to both perception and cognition) to manage visualisation of the specific interdependency concept within the human-computer interface.

2. STANDARD VISUALISATION PRACTICE.

Experienced construction process managers tend to regard the standard production process visual communication device to be the bar chart; a simple means of showing the basic nature of a production process. Perhaps unfortunately, it relies to some extent (different forms of bar chart vary in this regard) on the viewer's expertise to "fill in the gaps". This then raises the question of what it communicates to the novice, or inexperienced user, who does not posses the required expertise. Given that the first stage in the process of achieving cognition will be visual perception, there are three key theories that may be initially considered; physiological, psychological, and ecological (Moore, 2001). Two of these theories apply to bar charts: at the physiological level, the horizontal bars catch the eye's attention, and a quick scan by the viewer reveals they are of different lengths; at the psychological level, the number of individual bars provide some sense of the extent of the project, at least in terms of the number of activities it contains, and possibly of the complexity of the project.

A cognition problem with regard to the bar chart is that any form of interdependency between activities is implied (Gantt charts are less of a problem in this area), and therefore complete cognition relies upon the expertise of the user to 'add' the nature of interdependencies within a project to the chart 'as visualised'. This problem can be overcome to a limited extent for more experienced users by the use of a linked bar chart. However, the added links increase the complexity of the ambient optic array (the sum of all light energy having travelled between the surface's composing an individual's environment that converges at any given point within that environment) (Bruce et al, 1996). This leads to a trade-off between adding the extra information that can be utilised by an expert, and reduction of understanding by the non-expert (Field and Keller, 1998). At the same time the links are not, strictly speaking, signifying specific interdependency between individual activities. Rather, they signify relationships based on precedence and dependency without considering the full nature of that relationship. The appreciation of even such basic relationships requires reference to a further document; the work breakdown structure (WBS). Similar arguments can be made with regard to the various forms of network resulting from the use of the second type of visual communication tool; critical path methods (CPM). Figure 1 illustrates a section of a PERT chart as typically presented by project planning software. The critical and non-critical activities are clearly identifiable, and on this basis activities dependent upon each other are also identifiable. By further 'manual' interrogation of the data presented it is possible for the user to identify near critical activities themselves. The data presented remains insufficient for even an expert to achieve more than the most basic assessment with regard to the existence of either continuous or discontinuous specific interdependency between the activities. The form of presentation is therefore argued to contain "noise" that prevents full decoding by the receiver (expert or novice) of the data being communicated. This noise is suggested as being loudest at the visual perception stage of the cognition process.

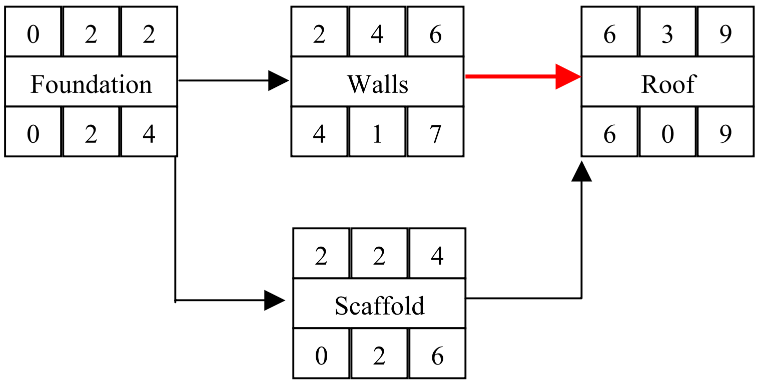

FIG. 1. Section of PERT chart

The question then becomes one of: are such charts (in their role of possible information visualisation tools), successful with regard to cognition of the production concept of specific interdependency, particularly DSI? This paper considers this question in terms of attempting to achieve successful cognition of the interdependency concept for both experts and novices. This is within the constraints of visuospatial perception as related to the use of charts, and the management of the human computer interface (HCI). The approach taken is one related to the area of research known as thinking with diagrams (TWD).

3. TWD, HCI AND CONCEPT EMERGENCE

Within the TWD umbrella of approaches, there is the suggestion that various forms of computer-based systems, such as pen-based sketching applications, can be developed to provide support for individuals as they attempt to clarify poorly defined concepts. Such support allows for an individual's need to produce a visual representation of the problem to be solved. This representation can then be perceptually responded to by the individual as they produce new shapes, each of which may represent a new idea about, or concept of, the problem. These new concepts are said to emerge from the process of perceptual response (Edmonds and Moran, 1999). In the situation where novices are being asked to consider the concepts of specific interdependency within, and discontinuity between, various activities for the first time, the nature of these concepts could fairly be argued to represent a problem of understanding for them. The resolving of this problem may be traditionally attempted by those with greater expertise through the use of bar charts and/or CPNs. The efficacy of such charts, with regard to cognition of interdependency concepts (such as DSI) has been discussed previously. A significant problem within the TWD domain has been noted as being the completion of numerous empirical studies investigating aspects of diagrams without any significant attempts to integrate the findings into an analytical framework: lots of studies; no general theory (Scaife, 1997).

The lack of general theory for TWD does not particularly apply to HCI approaches. A long established model which attempts to link perception, cognition, and memory in humans (Downton, 1991) is shown in Fig. 2. As far as HCI is concerned, the constraining aspect of this model is that of the low-capacity channel. The channel is deemed low-capacity in two respects: humans are unable to pay attention to all sensory inputs at the same time (this complements standard perception theories) (Milner and Goodale, 1995); sensory inputs are stored in symbolically coded forms, and the conversion rate from input to coded form is relatively slow. This has traditionally resulted in software designers seeking to observe a limited rate of data presentation. It is arguable that, with regard to production process data within construction projects, the limited rate of data presentation Is assumed to be achieved through simply replicating existing forms of data presentation, such as the bar chart; deemed by software designers to be known and accepted by the intended users of the software. By considering such charts in the context of TWD perspectives there emerges the possibility that they are insufficiently versatile to allow novices the opportunity to discover new ideas (shapes) concerning the problem facing them. There is therefore a need for those involved in the visualisation of information to consider more innovative ways of maximising the value of the information, and presenting it at a rate which humans are capable of encoding to form the relevant concepts. It is also important to note that encoding does not automatically ensure cognition. There is also the matter of noise to overcome.

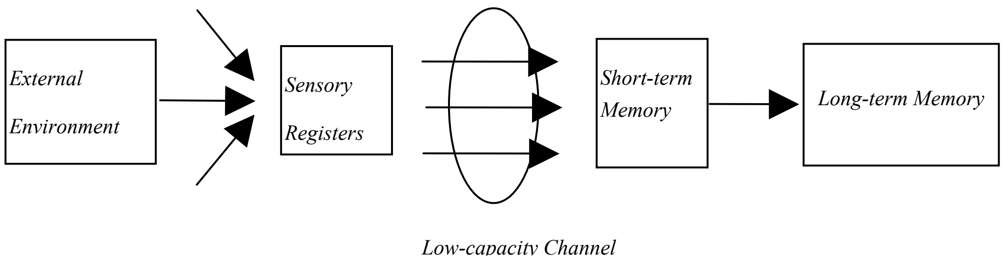

FIG. 2: Basic Model of Human Perception, Cognition and Memory (Downton, 1991).

One possible innovation is to consider allowing for the use of emergent shapes. A basic representation of the concept of emergent shapes can be achieved through consideration of a simple bar chart. A novice may well initially regard the chart as a series of bars without being fully, or even partially, aware of what the bars may signify. It has been suggested that a drawing is in fact a structured entity composed of a visual image and an associated verbal description of it (Finke, 1989). The bar chart can therefore be regarded as a structured entity. As the novice manipulates the visual image (activity bar length, location, relationships to other activities) new descriptions (structures) of it may emerge, and it is these new descriptions that are regarded as an emergent shape. In essence, the chart may look the same in that the bars remain at the same length and in the same position, but the description of it changes with each new emergent shape. New descriptions may well include the concepts of specific interdependency between the bars (activities), and of discontinuity as a basis for separating the bars from each other. This paper argues that such new descriptions should be regarded within the context of cognition on the part of the user, whether novice or expert. Further, it is posited that images traditionally utilised within bar charts, CPN/PERT charts, etc., may be enhanced to provide a more effective starting point for the development of emergent shapes.

4. COGNITION DEFINED.

This paper does not regard cognition as automatically flowing from perception. Three theories of cognition (Stark, 1996) can be considered:

Platonic theory - all infants come into the world with a complete set of ideals, each of which is awakened by experience of an actual example of that ideal.

Internal experience theory - propositional construction of internal cognitive models which can then tested against experience. If the model differs from the experience, new models are constructed by the human brain's near infinite ability to generate and evaluate cognitive models.

External experience theory - external experience flows inward, forming internal cognitive models, by some undefined process.

Of these perspectives, the internal experience theory is suggested as being the most valid with regard to the area of study covered by this research, in that it has the benefit of separating "seeing" (perception, although this need not be purely visual) from "knowing" (cognition). This approach also appears to be supported by the findings of researchers in the area of construction (Casakin, 1998), who found that expert and novice student architects achieved differing levels of success in the use of analogy in problem solving. Expert architects were more readily able to transfer principles identified from diagrammatic sources to the solving of problems. Casakin suggests that the key issue was the differing levels of experience between the two types of subject. This in turn reflects one of the arguments typical of TWD research; rather than investigate how novices respond to a limited number of diagrammatic forms the emphasis should be on how experts use a great variety of diagrammatic forms (Scaife et al, 1997). Pre-existing methods of utilising diagrammatic forms to communicate the concept of DSI in particular have previously been noted as being reliant upon a level of knowledge not typical of a novice. However, this should not be taken to mean that existing diagrammatic forms (such as PERT charts) can not be enhanced to represent an acceptable visualisation of expert thinking, particularly with regard to the concept of DSI. Such enhancement may then pose problems for software designers with regard to how such an approach can be allowed for within the human-computer interface.

This paper examines one possible form of structured entity that could be expected to enhance the process of cognition (based on internal experience theory), and examine issues relevant to the engineering of the HCI so as to allow users to utilise the benefits of structured entities.

5. EMERGENCE AND PERCEPTION.

Accepting that emergence is possible evidence of cognition, researchers in TWD suggest that the issue of shape grammar is an important one with respect to how humans interact with drawings (Chase, 1999), an issue that is particularly problematic as design processes become increasingly computer based. The activity of graphic design, when paper-based, supports an infinite number of opportunities for emergence, but when computer-based is deemed to support a finite number of opportunities for emergence. This problem is related to the extent of detail provided by computer hardware which, when using project planning software results in "projectitis" (the inability to view all the detail of a project on a computer monitor at one time), to the detriment of the user's overall cognition of a project (Moore and Hague, 1999). Through focusing on sections of a project network where specific interdependence can be identified, the impact of the projectitis problem should be reduced. How then can such a focus be achieved?

The mechanics of perception are generally regarded as having evolved to ensure greater attention for moving objects in the visual array than to stationary ones. Frogs, for example, have no response at all to stationary objects in their visual field and respond only to movement. However, this is generally argued as relating to the need to survive; a moving object is more likely to represent a threat than a stationary one. There is therefore little to link perception's preference for movement in the visual array to the extent of cognition regarding a particular problem. A further consideration in this regard is that the arrival of animated representations, as in films, cartoons, simulations etc., within the visual environment is a relatively recent phenomena. Given this situation, techniques have been developed that allow static (albeit paper-based) representations to become sophisticated tools in the design process. Some researchers have gone so far as to claim that all the most creative epochs in human history exhibited a common feature; a natural or experimental philosophy which fuelled the development of the culture utilising it, on the basis of the diagram (Albarn and Smith, 1977). This context regards diagrams as being a combination of a variety of communication functions such as verbal, numerical and visual functions, etc. The common basis of these functions is suggested as being the presence of pattern, and this is one of the key considerations in the development of the proposed structured entity.

Some patterns are sufficiently sophisticated to make use of both perception and cognition theories to fool the brain into seeing something that is not actually there. This seems to depend upon the interaction between cognitive models and internal experience as discussed earlier, and an example of which can be found in the so-called Muller-Lyer figure (Fig 3). Dependent upon the internalised experience of an individual they may perceive the images as being the corner of a room and the corner of a building respectively; meaning is added as a result of the boundaries of experience. Those dealing with the visualisation of information cannot fully be aware of the range of experiences internalised by each member of their potential audience.

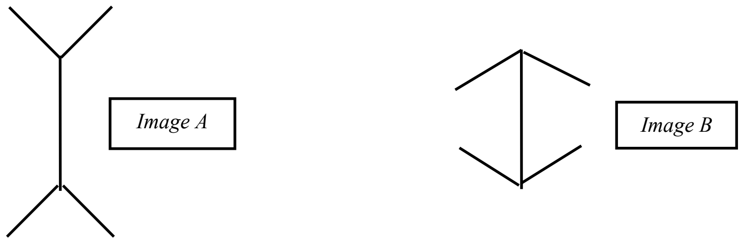

FIG. 3. Example Muller-Lyer figure

A more powerful pattern can be found in an experiment carried out by Gregory (Albarn and Smith, 1977) in which the images in figure 4 were projected onto a screen in a manner that made the viewers perceive the black images as fused and standing away from the screen, and the white centre triangle (that does not really exist) as also standing away from the screen. This type of pattern triggers what is referred to as cognitive perception, in which 'normal' perception is overridden and cognition adds non-existent information to the actual data and results in a spurious (but perhaps intended) meaning being attributed to the pattern. The significance of the concept of internal experience theory to the process of cognition therefore increases in that cognitive perception appears to work from the base of prior experience which the brain attempts to utilise when carrying out pattern recognition of a structured entity. During this process the viewer of the entity may “see” almost every configuration of pattern that it is possible to derive from that entity as they struggle to apply meaning to it. The longer the viewer is exposed to the entity the more certain combinations of pattern begin to dominate the process, reappearing more frequently to the viewer. Unless this process can be concluded satisfactorily, the original entity may be regarded as unorganised and meaningless (Albarn and Smith, 1977). The suggestion therefore becomes one of how pattern can utilise previous experience so as to guide the viewer towards the required cognition.

During the act of cognitive perception there is evidence that the brain searches for familiar images through the action of developing scanpaths across the entity being viewed (Starck and Choi, 1996). In a bar chart for example, most novices would recognise the horizontal bars as a familiar pattern but may not recognise that these particular bars do not posses the same representational meaning as their previous experience of such an entity may lead them to expect. Considerable effort may be expended in examining “attractive” elements of those parts of the visual array occupied by the bars so as to determine their most likely meaning. Much of this effort appears to be involuntary and occurs through a mechanism identified over 50 years ago and referred to as the visual grasp reflex (Hess, 1946).

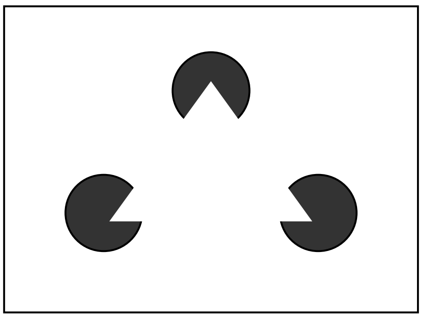

FIG. 4. The White Triangle

The most significant difficulty in achieving the desired form of cognition, in the context proposed here, is possibly that the HCI simply can not “know” the nature and extent of each user's prior experiences (particularly if they range from novice to expert) that may affect cognitive perception and result in “incorrect” cognition. There are suggestions that artists have, over time, been aware to some extent of this process of pattern recognition and the possibility of incorrect cognitive perception. Durer, for example, believed that the ideal nude figure (a structured entity) could only be produced by taking the face of one subject, the arms of another, the legs of a further subject, and so on (Berger, 1972). Perhaps Durer was simply trying to give the widest possible opportunities to his audience to achieve pattern recognition based on experience?

6. A POSSIBLE STRUCTURED ENTITY

The paper has identified a number of components forming the cognition process. While none of these factors are new of themselves, to date they have arguably been addressed in a piecemeal manner. The author posits that a cohesive cognition-oriented strategy for the utilisation of information that many current project planning software packages have the facility to support, will result in a more powerful visualisation tool.

Traditionally, specific interdependence relationships within production processes arise from the identification and utilisation of three categories of process resource: labour, plant and materials. Many software packages will allow resource data of this type to be entered. They will then also produce resource charts/histograms showing peaks and troughs of resource demand over a project duration. Two perception/cognition problems can be identified in this regard; the resources tend to be treated as being homogenous within each category (bricks and concrete are both regarded as being materials; bricklayers and roofers are both regarded as labour), and it is difficult to focus on the relationships between small numbers of activities within the overall resource histogram as shown in figure 5. In order to identify and manage effectively areas within the project where DSI exists as a potential problem, the treatment of resources as being homogenous needs to be overcome within the visualisation of the project activities and their relationships. A suggested approach to overcoming homogeneity utilises the ability of both humans and computer software to carry out pattern recognition.

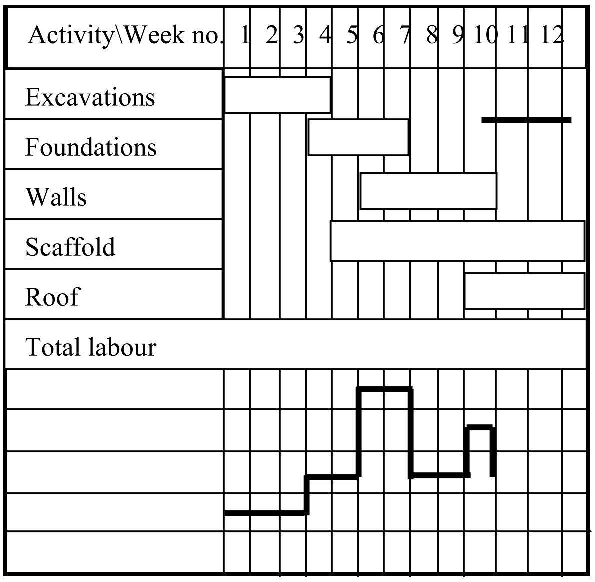

FIG. 5. Resource Aggregation Chart

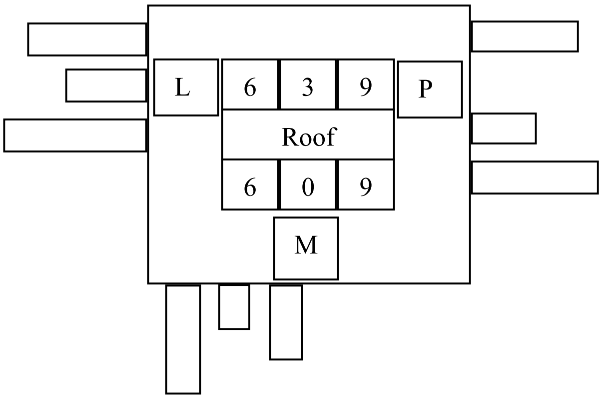

FIG.6: Basic Form of Proposed Structured Entity

Figure 6 presents a possible basis for a structured entity that brings the above considerations together as a development of the pre-existing PERT format. The intention in using this format is to minimise the work required in revising the HCI. The structured entity represented within figure 6 contains 'drawn' information which functions as the basis for pattern recognition, and 'written' information that supplies supplemental detail concerning the individual activity. It is suggested that a consistent structuring of the information is essential if pattern recognition is to be utilised. On this basis each side of the activity entity relates to a specific resource, and this is consistently applied to all entities. The right-hand side, for example, will always hold information concerning plant resources, and this is presented in a similar manner to that used in resource aggregation charts discussed previously (scaleable blocks of quantity for each type of plant resource). Lower and left-hand sides will likewise hold information concerning materials and labour resources respectively. Once this format is established it then becomes feasible to search the network of activities for similar patterns of resources required for the completion of activities. As far as DSI is concerned the emphasis is on looking for *disruptions* to patterns within activities in close proximity to each other, irrespective of whether they are on a critical path or not. Figure 7 illustrates four activities that are in close proximity to each other.

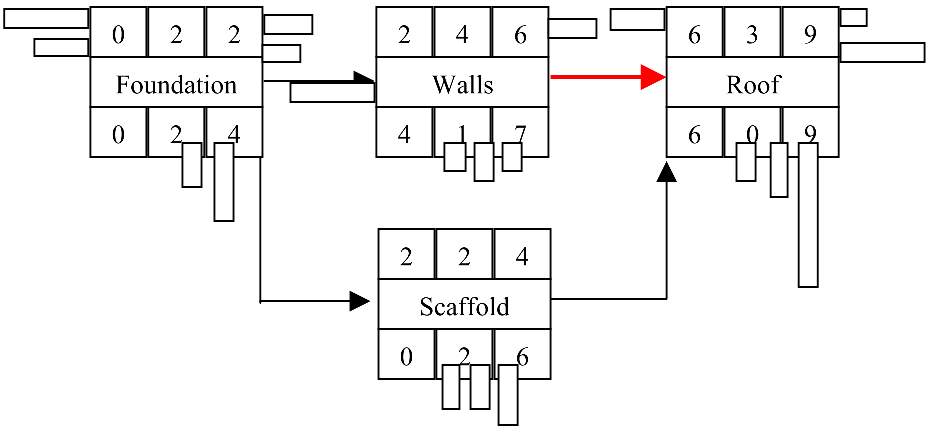

FIG. 7. Proximate activities

A rapid scan of the activities in figure 7 should trigger the visual grasp reflex discussed previously and cause the eye to look in more detail at “unusual” features within the visual array. In this case the roof activity should be one of the first activities to be examined in detail, particularly the facet dealing with materials. This stands out due to its comparatively large requirement for one specific material type. A scanpath is then built up around the various activities as cognition is attempted on the basis of searching for patterns. This should lead to the conclusion that there are no significant similarities (with regard to type and quantity of resources) between any of the activities. Because evidence of continuous specific interdependency cannot be established (no clear pattern) within the activities, there can therefore be argued to be the basis of discontinuous specific interdependence within the group of activities. The planner/manager is then alerted to the possibility that these particular activities have the potential to cause greater than normal problems of control (interfacing of differing materials, plant and labour requirements). Such cognition would not be achieved with the traditional PERT visualisation format. However, this is not to say that cognition cannot be further enhanced by utilising the ability to identify near-critical activities on the PERT basis of variance and float relationships.

A further advantage of the proposed approach is that the resource data visualisation facility could be clicked on or off as required by the user. However, the points noted previously with regard to the lack of studies on the efficacy of such formats still apply, and such studies are proposed as part of the ongoing research programme.

7. CONCLUSION.

The paper examines the act of visuospatial cognition and introduces the possibility of incorrect cognition through the presentation of structured entities which individuals may perceive in differing manners. This possibility arises from consideration of work carried out within the area of research referred to as thinking with diagrams, which utilises the concept of emergence as individuals attempt to use analogy within the process known as cognitive perception. Analogy is important in that it can be clearly linked to the theory of internal experience in which individuals construct internal cognitive maps of entities based upon previous experience. The problem faced by the HCI designer is one of not knowing what any given individual's prior experiences have been, and how they may subsequently bring about "correct" or "incorrect" cognition is raised as being significant. The paper suggests a visualisation tool to address this problem.

8. GLOSSARY

Specific interdependence. The existence of a dependency link or links between one activity in a process chain within a project and one or more other activities, in one or more other process chains in that project and/or in other projects.

Dependency (normal). The reliance placed by one activity on the completion of one or more immediately preceding activities in a project before it can commence (a finish-start relationship).

Design. The making of decisions concerning a structured entity.

Continuous interdependence. The existence of minor differences in the resource requirements for interdependent activities.

Discontinuous interdependence. The existence of major differences in the resource requirements for interdependent activities.

Precedence. The need for certain activities to be completed before other activities within a project.

9. REFERENCES

Albarn, K and Smith, J.M. (1977) *Diagram. The Instrument of Thought*. Thames and Hudson Ltd., London.

Applied Learning Labs (2002) www.appliedlearninglabs.com/kmaps

Berger, J. (1972) *Ways of Seeing*. British Broadcasting Corporation and Penguin Books Ltd, London.

Bruce, V., Green, P.R. and Georgeson, M.A. (1996) *Visual Perception: Physiology, Psychology and Ecology*. Psychology Press, Hove.

Casakin, H. (1998) Diagrams, Sketches and the use of Analogy in Design Problem-Solving: Experts and Novices. Proceedings, TwD98, University of Wales, Aberystwyth. August 22-23 1998.

Chase, S.C (1999) Emergence, Creativity and Computational Tractability in Shape Grammars. Proceedings, Chi Workshop at http://bashful.lboro.ac.uk/chi-wshop/Proceedings/Edmonds.html

D'Herbemont, O. and Cesar, B. (1998) *Managing Sensitive Projects*. MacMillan Press Ltd, London.

Downton, A. (1991) *Engineering the Human-Computer Interface*. McGraw Hill, London.

Edmonds, E.A. and Moran, Thomas. P. (1999) Interactive Systems for Supporting the Emergence of Concepts and Ideas. Proceedings, Chi Workshop at http://bashful.lboro.ac.uk/chi-wshop/Proceedings/Edmonds.html

Field, M. and Keller, L. (1998) *Project Management*. Thomson Business Press. London.

Finke, R.A. (1989) *Principles of Mental Imagery*. MIT Press, cited in Edmonds and Moran (1999).

Hess, W.R., Burgi, S. and Bucher, V. (1946) *Motorische Funktion des Tektal and Segmentalgebeits. Monatschr.* Pyschiatr. *Neurol*. 112. (cited in Milner and Goodale, 1995).

Miller, E.J. and Rice, A.K. (1967) Systems of Organisation, Tavistock Publications, London.

Milner, A.D. and Goodale, M.A. (1995) *The Visual Brain in Action*. Oxford University Press, Oxford.

Moore, D.R. (2001) Visual Perception Theories And Communicating Construction Industry Concepts. *Work* Study, (50), 2. MCB University Press, Bradford.

Moore, D.R and Hague, D.J. (1999) *Building Production Management Techniques*. Addison Wesley Longman Ltd, Harlow.

Scaife, M, Cheng, P, Lowe, R, Rogers, Y and Rosenberg, D. (1997) TwD: in the Head or in the World? Proceedings, Thinking With Diagrams, University of Portsmouth, Jan. 9-10 1997.

Starck, L.W and Choi, Y.S. (1996) Experimental Metaphysics: The Scanpath as an Epistemological Mechanism. In Zangemeister, W.H, Stiehl, H.S and Freksa (1996): *Visual Attention and Cognition*. Elsevier Science B.V., Amsterdam.

Walker, A. (1996) *Project Management in Construction*. Blackwell Science Ltd., Oxford.