EVALUATING THE COMPLEXITY OF CAD MODELS IN EDUCATION AND PRACTICE

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Abstract. When educators or students estimate the complexity of proposed CAD projects, in order to judge feasibility, two conceptions of complexity may be considered. The first, design complexity, based on visible features of the object to be modelled, is the easier to assess beforehand, but is not very reliable. The second, CAD complexity, based on the actual CAD embodiment of the design, is suggested as potentially a more useful guide, in spite of evident difficulties with assessment in advance. Clearer articulation of this under utilised concept is proposed for both educational and more general reasons, and this becomes the focus of the paper.

1. Introduction

A frequent culmination of computer aided design (CAD) teaching is the self-directed project, for which a student produces a CAD drawing or model. Each student is required to select a suitable design, and then to develop and implement strategies to produce and display their model. During discussions with students, on choice of project and their general approach, matters of complexity inevitably enter discussions. For any individual there is an optimal range of complexity. A too modest project may fail to challenge and extend, if the potential to extend the individual’s technical knowledge is not exploited. An over complex undertaking, if not recognised and corrected early, may consume many hours of effort, much of it fruitless, leaving the individual frustrated, demoralised and mistrustful of CAD technology.

Two interpretations of complexity are often discussed at the outset, namely design complexity, based on the appearance of the object to be modelled, and CAD complexity, based on the actual CAD embodiment of the design.

Design complexity is the more popular indicator of manual drafting task magnitude, because it is visible before work commences. But appearances can be misleading, especially in CAD production, where magnitude of a task is highly dependent upon interpretation, what the designer chooses to model and chosen methods of representation. Superficial aspects of drawings and photo-
graphic images can mislead and short-circuit a designer’s detailed analysis and planning at the commencement of their CAD task unless they are balanced by equally clear notions of the intended model.

CAD complexity is associated with the actual CAD embodiment of the design. It derives from the strategic use of CAD functions applied to both organisation and production of the completed model. It is potentially a more useful notion than design complexity, because it directly concerns task outcomes, but it appears to have been under-utilised. There are several reasons why this may be so. First, the concept of complexity is not entirely clear (Corning, 1988). CAD complexity is even less clear, being easier to describe in the negative, by defining what it isn’t rather than what it is. Although there is an abundance of published literature on complexity in general, much is about complexity in nature and relatively little is relevant to CAD. There is a need to clarify the sense of the term.

Another difficulty is that CAD complexity is not evident from the appearance of drawings generated from a completed model. Other indicators, such as the number of files or file sizes are no more revealing, unless some account is taken of the file contents. There is a need to identify the essential components of complexity.

Informal observations of hundreds of students undertaking CAD courses, in the Faculty of Architecture at the University of Sydney, indicate that many find it difficult to appreciate broader organisational aspects of CAD, until their work is well advanced. A likely reason for this is a need to experience the consequences of different strategies in order to understand their significance. The possession of a tangible model-in-progress to see and discuss is obviously helpful as well. To bring tangibility to the start of projects there is a need to develop a consistent and coherent nomenclature of CAD complexity in a form that can be presented and understood before modelling commences.

Greater understanding of CAD complexity may also be useful to performance of a range of, short term to long term, management activities in educational and other settings. Educational tasks include; a) matching project complexity to student knowledge and skill levels more accurately at the outset of a project, b) developing bases for modulating complexity during the course of a project, and c) developing objective criteria of use in comparison and assessment of completed CAD models. Other more strategic uses could include support for the development of; a) bases for evaluating and coordinating the integration of CAD and related software,
2. Concepts of Complexity

To initiate the study, concepts that have been identified as important in reaching a working understanding of CAD complexity are first defined and then brought together progressively. In this paper the term “CAD model” refers to one or more computer files that are intended to describe or represent the visual, or any other, properties of a design.

2.1 COMPLEX AND COMPLEXITY

The adjectives representing the focus of this paper are defined in the Webster Universal Dictionary (Wyld and Partridge, 1975) as follows:

complex: "Composite, complicated, consisting of two or more closely connected or interwoven parts, elements, strands &c.: not simple"

complexity: "State or quality of being complex; intricacy."

2.2 RELEVANT COMPLEXITY

Although the broad sense of complexity is defined it is still necessary to evaluate a variety of common interpretations of the term and select only those which are relevant. These are described below.

2.2.1 Degree of Difficulty. It is recognised that complexity of a CAD task is associated with difficulty. Complexity influences difficulty. However as many other things also influence task difficulty, this relationship is not explored any further in this paper.

2.2.2 Real Complexity. There is a difference between complexity, which is real or objectively measurable and substantially irreducible, and apparent complexity, which is a matter of perception and interpretation, varying from one person to another. The objective in this paper is to identify real complexity.

2.2.3 Necessary Complexity. Human artefacts typically contain both necessary and unnecessary elements, both intended and unintended. The CAD complexity of this study is that which may be regarded as intended and necessary. This paper does not explore the area of CAD intentions but
acknowledges that CAD models produced for one purpose are frequently put to other uses.

2.2.4 Organised Complexity. Reference is made to the distinction between disorganised and organised complexity made by Weaver (1948). Since CAD models are ordered systems, the objective in this paper is to identify organised complexity.

2.3 COMPLEX SYSTEM

CAD models are systems, to the extent that they combine any of the above attributes of complexity within some integrated form. This is clear from the following definitions, found in the Fontana Dictionary of Modern Thought (Bullock and Stallybrass, 1977) and the Webster Universal Dictionary:

System: "group of related elements organised for a purpose." (Fontana) and "group, association, aggregation, of things or objects, between which there exists connection, relation, interaction, and which together form a unity." (Webster)

Complex CAD models are complex systems, based on the description of complex systems by Simon (1996, p.183), to the extent that they are "made up of a large number of parts that have many interactions."

2.4 ORDERED SYSTEM

Research into complex systems has been stimulated in recent years by studies of chaos. One outcome of this research has been a greater interest in the study of complexity in its own right (Simon, 1996, p.181; Salingaros, 1997) including the study of complex systems that are ordered and not at all chaotic.

It is proposed that CAD models, at least as we currently understand them, belong in the latter group, in both: a) design complexity, since order is normally an objective of design; and b) CAD complexity, since the CAD model is an embodiment of some form of order. It is acknowledged that this need not always be true. Some aspects of design complexity, and some
functions of CAD modelling, such as surface representation, may involve intentional chaos or utilisation of chaos, for artistic purposes, for example.

2.5 DESCRIBING COMPLEXITY

Simon (1996) includes the following characteristics, in a series of observations about complex systems:
- Complexity of a system depends critically upon how it is described.
- Most complex systems contain a lot of redundancy.
- Simplicity of description can be achieved by finding the right representation.
- Hierarchies of complex systems can often be described in economical terms.

Applying these observations to CAD models one may conclude that a practical first step, towards achieving an economical description of CAD complexity, is to identify CAD hierarchies.

2.6 CAD COMPLEXITY

Complexity of a CAD model is influenced by design complexity to the extent that properties of the design or modelled object are represented in the CAD embodiment. It may be inferred that the distinguishing elements of CAD complexity must derive from something other than these properties. Looking beyond the properties, it is evident that a CAD embodiment is a representation of an object, either whole or part. It is equally clear that similar objects may be interpreted and represented in different ways by designers, for an infinite variety of reasons and by CAD systems, simply as a result of variations in functionality. Looking at this another way, one could observe that distinctions between CAD embodiment and the designed object arise from the fact of representation. Therefore, it may be expected that distinguishing elements of CAD complexity will arise from characteristics of CAD interpretation and representation.

2.7 SOURCES OF CAD COMPLEXITY

Three possible sources of CAD complexity can be distinguished: CAD data, or the information content of the CAD model; CAD structure, associated with the CAD model file organisation; and properties associated with application software functionality. These are described in greater detail below.
2.7.1 CAD data. Items in this category include the actual ingredients of the CAD model, consisting of shapes and notations:

- Shapes or figural information includes vectors and inserted raster images. Graphic symbols, such as North points and hatch blocks may also be considered as belonging to this category.
- Notations include dimensions, other numeric data, and drawing notations, such as headings, notes or title blocks. Also included is documentation to facilitate communication, but not necessarily part of the model.

Measures of CAD data include quantities such as, numbers of objects, numbers of different objects, shape complexity and properties other than shape, including end points and scale factors. In measuring the complexity of notation, fonts, scales and other properties to meet different presentation requirements are relevant. Further distinction can be made between data that is part of the design and data that is part of the presentation of the design, although this is not crucial to the main ideas expressed in this paper. Of greater importance is the fact that CAD data in its raw form is, highly repetitious, difficult to analyse and arguably reflects design complexity more than CAD complexity.

2.7.2 CAD structure. Items in this category include file variables and inter-file variables:

- File variables include functions that support differentiation and organisation of data within individual files, such as colours, line types, layers and complex objects. Measurement of complexity may be similar in principle to that employed to measure CAD data.
- Inter-file variables include functions that support organisation and referencing of data from file to file. Typically files are of the same type. Different types of files normally require interfacing and sometimes translation of data from one form to another.

CAD model structural elements, of the kinds briefly referred to above, are highly capable of analysis and decomposition by reference to CAD functions. Many support hierarchical organisation. This renders them suitable for use in developing a description of CAD complexity, based on organisational sub-systems, that follows the next section.

2.7.3 Application software. CAD software products vary significantly, in extent and manner of supporting CAD production, editing and display functions. This influences not only how things are done, but also what is done. Product variation is not discussed in this paper, given the large number of different CAD products and different versions.
Applicable to all of the above sources of CAD complexity is the use of multimedia data, through use of applications such as VRML. Reversal of the practice of including CAD information in multimedia presentations to, instead, incorporate multimedia into CAD models is still at the novelty stage, but can reasonably be expected to become significant in the future. However, this study focuses on current applications.

To provide an indication of the manner and extent of software variations two popular, vastly different CAD applications, namely AutoCAD Release 14 and ArchiCAD Version 5, are referred to in the next section, either by name or as the ‘CAD packages.’ Significant differences of approach and function are highlighted where appropriate in the description of each of the organisational sub-systems.

3. Subsystems of CAD organisation

It has been established that CAD files are complex hierarchical systems. In addition, aspects of complexity of varying degrees of significance have been introduced.

It is possible from this point to identify and describe various CAD model hierarchies. In the following description, five subsystems of CAD organisation have been categorised on the basis of organisational processes. There are four categories listed in order from low to high level of organisation. This order also coincides (broadly) with least to most technically advanced, and least to greatest potential to provide high levels of model realisation, at high levels of efficiency.

A fifth category is included to incorporate peripheral factors which are integral to the communication of a model, but are not part of the model.

3.1 OBJECT DIFFERENTIATION

Differentiation is an elementary, one level (or non-hierarchical) structuring that implies grouping within a model file. It may be achieved by varying one or more appearance characteristics, enabling a person to visually identify different classes of element, or particular parts of a model. The main characteristics include:

3.1.1 Shape. Different shapes can represent different objects. Proximity and orientation of shapes to each other or to some ordered form, such as a grid, may also be employed to assist recognition.
3.1.2 Colour. Variation in hue, saturation and other object colour properties enable different classes or conditions of objects to be visually distinguished regardless of shape. AutoCAD and ArchiCAD associate colours with pens, by default, enabling printed line thickness to be modulated by means of colour.

3.1.3 Line type. Particular repeating patterns of shorter lines, dots, symbols and spaces are well suited for visually distinguishing linear objects, such as centrelines, especially when these overlay other objects.

3.2 OBJECT GROUPING

Grouping is a method of relating objects within a model file, to act as one, by means of one or more of the following functions:

3.2.1 Informal or unnamed grouping. Both CAD packages support informal, one level groupings, but in two different ways.
- AutoCAD ‘polylines’ may be drawn as a continuous string of lines or formed by converting a series of end-to-end objects into a complex polyline.
- ArchiCAD ‘Drafting Modifier’ option permits designer to draw a continuous string of lines. These may be converted into one continuous object, through use of one of the ArchiCAD building tools, e.g. ArchiCAD Slab tool.

3.2.2 Formal object-class grouping. Many CAD applications, including AutoCAD and ArchiCAD support open ended class groupings by permitting designers to assign and reassign elements to particular named layers. Use of layers enables designers to control display properties, such as colour and line type, and selection properties of different classes of design elements. Layer hierarchies, of two or more levels, can be created by the use of layer name conventions.

3.2.3 Formal or named-object grouping. The ability to group objects and build complex hierarchies of nested objects has long been associated with drawing applications. Use of named ‘blocks’ in AutoCAD, to modularise a design, enables designers to achieve significant economies of file size and to simplify the production and editing of a CAD model. Different blocks need have nothing in common. However, it is possible to build up complex hierarchies based on consistent sub-components.
3.3 FILE GROUPING

CAD models requiring more than a few hours to produce, or more than one author, soon warrant organisation of objects and their representation into more than one file. ArchiCAD supports file grouping by means of a class of files called Library files, which are an alternative to the AutoCAD use of blocks. AutoCAD External Referencing allows any drawing file to be ‘attached’ to any other. On large projects external references may take the place of blocks, to eliminate duplication. Both packages allow hierarchies of attachments to be developed and include validation procedures to prevent circular referencing.

3.4 APPLICATION GROUPING

It is evident that there is a general trend in the evolution of computer applications toward increasing complexity and functionality. Indicators of this trend include the constantly increasing physical size of each year’s new software packages, their occupation of progressively more disk space and ever increasing demands on memory and processing. Associated with the general growth is a growing mobility of data between associated applications.

Creation of links joining CAD software and data base or spreadsheet applications is now a common technique. A more recent trend toward the development of more sophisticated dynamic models, capable of simulating complex facilities, will further stimulate multiple file and application structuring, making this a very fertile source of new hierarchies.

3.5 PRE-SETS

Selection, simply as an activity, is not a factor in CAD complexity. However pre-defined settings to display or suppress the display of objects facilitate communication of a substantial model. While not part of the model, pre-sets act as agents for the expression of the organisational hierarchy contained within model files. Being both separate and relevant to CAD complexity they are therefore included in this section. Examples of pre-sets include the following:

3.5.1 Filter lists. Filter options in AutoCAD permit designers to limit the display of different classes of object, based on colour, line type and other more abstract properties, such as location, current in-use status, or their association with externally referenced files.
3.5.2 Layer Sets. Combinations of layers in ArchiCAD files may be defined, named and saved, as named layer sets in the Layer Menu.

3.5.3 Named Views. The View command in AutoCAD permits designers to pre-set combinations of viewpoint coordinates, orientation and zoom settings and to save these in the form of named views.

3.5.4 Other Display settings. Other important presets, which can not be described more fully at this time, are the pre-set page layout functions, which include ArchiCAD Plotmaker and AutoCAD Paperspace.

4. Concluding statements

The CAD subsystems described above provide a basis for measurement of five different aspects of complexity. Within each there are more variables to measure. Selection of particular measures and evaluation, or speculation, of how they may be weighted to produce some complexity quotient, is beyond the scope of this paper, but some brief observations are worth making.

Complexity, like intelligence, or the world’s weather, includes interdependent components and others that act separately. Unlike intelligence, CAD complexity itself is not an objective. The objectives are to optimise and manage complexity. Unlike the weather, complexity can be controlled. Measurement of CAD complexity is fundamental to both optimisation and control. In future research attention will focus on relationships between the individual subsystems of CAD organisation, design type, model scope and other CAD requirements.

The implications of these observations extend beyond the educational context. Ultimately, CAD is about communication, and that is changing everywhere as technology progresses. CAD usage is evolving beyond single task "throw away" functions, of project-based design and construction, towards interoperability and longer-term applications, such as large-scale system simulations and facility management. Interoperability requires greater consistency in the use of CAD as well as the design of CAD software. Longer term applications demand both consistency and durability of CAD models. As these factors grow in importance so will the need to further develop and refine principles and concepts of CAD organisation, based on objective measurement.
References


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