GIS Software and Coordinated Project Information Systems, a mechanism for increasing the effectiveness of 3D CAAD Models.

John A. M. Counsell

University of the West of England, Faculty of the Built Environment, Frenchay Campus, Coldharbour Lane, Bristol, BS16 1QY.

Abstract

This paper reviews current 3D CAD building modelling by reference to a large on-going case study, in which 3D building models and sites are used to generate co-ordinated drawing, schedule, and visualisation output. It focuses on barriers which current software interpose, preventing more complete use of 3D CAD to integrate building project information systems. Comparisons are made with tools and methodology developed in GIS, in which users make different selections as required from common databases, and It is argued that used in conjunction with 3D CAD building models, they could improve functionality and reduce barriers to effective deployment.

Keywords: Building model coordinated information systems

1. Introduction

Practising Architects normally create three dimensional computer aided design (3D CAD) Building Models to generate visualisation. Their purpose is either to acquire design feedback, assist design communication, convince third parties of the value of the proposed building, or present difficult to achieve views of existing buildings. Less often, such models are also used to generate construction drawings, and to provide schedules for Bills of Quantities.

3D Building Models, used to generate drawings and schedules, serve as a skeletal coordinated project information system. Recent use for this purpose has highlighted a number of problems and deficiencies, which serve to define future needs. These needs may be better met by the development and application to 3D CAD of tools already applied in Geographic Information System software (GIS), than by predicted developments in CAD software.

2. Case Study [1]

Westbury Homes embarked upon a large-scale commercial application of building modelling in 1990.[2] The generation of visualisation, schedules, Bills of Quantities, and conventional drawings from 3D CAD models was successfully prototyped in months. Eastman defined the goal of building modelling in 1991 as 'for the computer to take over the translation and coordination issues among the multiple representations used in design.'[3] Westbury's purpose was to capture data at source that would feed all downstream systems. In effect the 3D CAD and the downstream systems would comprise a building project information system. Their Information Technology Director said that "We don't see CAD in isolation, but as part of a larger whole, it is the driving point in a series of linked computer systems which all share the same information. All the data is stored in a single location and is sent 'down the line' to departments responsible for aspects such as land buying, production control and finance."[4]

Over three years Westbury proved and completely superceded previous systems with building modelling in all the regional offices, linked by local and wide area networks for trans-regional group working. Group working created a single central source library of CAD components, from which were built up hundreds of complete template buildings, updatable by any regional user and available to all. Now template building models are adapted to local conditions. Buildings, sites, and siteworks are married automatically to local specifications and costs. The systems are used and the users would not choose to abandon building modelling. Yet the limitless promise has proved restricted, partly due to cultural resistance, but substantially due to detailed failures of the software to support the needs of the users.

3. The Nature of Geographic Information Systems [5]

GIS are seen as a special case of Information Systems in general. It is an important feature of GIS that the results of queries by an interactive user can create new data, fed back in to enhance the database. Their methodology offers useful parallels to 3D CAD based information systems. GIS have been characterised as interactive, multi-user, graphic systems, storing and supporting the rapid processing and display of large datasets, and dependant above all on tailored Database Management Systems (DBMS) supporting locational and multi-dimensional data and distributed databases. [6] Because of the enormous cost of data input it is normal for many users to have access to the same sets of data, to recoup costs of entry through repetitive use.

The addition of analytical operations to either cartography, remote sensing, database management or CAD system software has been identified as GIS. [7] 3D CAD in general lacks the analytical tools, and GIS lacks the 3D sophistication, since a focus on maps leads at best to an extrusion upwards from 2D forms, a form of 2½D. GIS offer an accessible repository for integrated data, the foundation of coordinated information, yet few are designed to handle true 3-dimensional data. [8]

The various ideas about GIS were synthesized and presented by Maguire, in the form of three distinct but overlapping views ...termed the map, database and spatial analysis views. [7] In this definition the map view is based upon datasets held in layers, manipulable and combinable to generate new maps with various contents and scales. The database view is focused on storing, searching for and retrieving spatial information, through the frequent use of simple queries; while the spatial analysis view sees GIS as the application of tools for spatial analysis and predictive modelling. All these views may be facets of the same system, differentiated by the needs of the user.

User needs are seen to develop through three generations, starting with: 1) assembling, organising and undertaking an inventory, this would be of features of interest, enabling simple data queries about location or condition; 2) analyses, such as optimal locations for a specific use, or trends revealing change over time, based on the gathered inventory; and 3) when the information system evolves from a transaction processing system to a strategic management support system, assisting to define optimal routes, demonstrate patterns, and answer 'what-if' modelling questions. Many of these needs are similar where building models are used to coordinate building project information systems, when I do not believe we have the facility for or have completed the initial inventory of features of interest, upon which further analysis would be based. Categories of information systems were defined by Björk, who distinguished facts, constraints and knowledge. We have still to record sufficient facts. [9]

The lowest common denominator of needs for a 3D CAD system is probably visualisation.

An isolated workstation can be used to plot useful images or drawings. Hence development concentrates on publication of drawings, pictures or animations, using surface-modelling and drawing-publishing rather than building description tools. The closest GIS parallel is the map view. 3D CAD similarly uses layers to publish high quality targeted drawings from various combinations of datasets. Modellers gain from increased co-ordination of different targeted drawing packages, from increased quality due to the ability to build solutions on the screen before building commences on site and so resolve problems in advance, and sometimes from increased speed of amendment in re-generating assuredly synchronised output automatically. Little attention is paid to the database view, because those users who might frequently search for and retrieve spatial information using simple queries, use the published drawing or schedule output to do so, rather than the CAD system. Even less attention is paid to the spatial analysis view. Goodchild defined spatial analysis as 'analytical methods which require access to both the attributes of the objects under study and to their locational information.'[[10]] Attributes which adequately describe the building project are seen as secondary to locational graphics, in 3D CAD practice. Lacking adequate description, there are still few practical integrated tools to analyse the developing building model, predicting cost, materials life, energy use, usability of space, maintenance or safety implications, or alternative solutions.

4. Common Information Models

Westbury Homes sought to create a common information model. The CAD systems used did not enable full integration into the downstream systems. The external DBMS was at best grafted on, the internal CAD database was completely isolated within an inaccessible black box providing severely limited functions. Sending data 'down-line' automatically was possible, but re-integrating the results into the CAD system was arduous. The information model that resulted was dis-integrated. CAD Systems were considered, by Newell and Theriault in 1990, to have only rudimentary links to databases which typically might contain parts listings or stock reference numbers. [[11]] I have seen few signs of change. Use of DBMS is downstream only. It is possible to download lists or reference numbers to a larger database containing specification and cost data, to output a detailed composite report, such as Bills of Quantities. The lack of integration of DBMS hinders amendments to details in the wider database being readily used, to update or control the contents of the CAD model and its graphical display.

There have been a number of recent definitions of a single building model, ranging from the Swedish KBS Model to the ICON model at Salford University. [[12]] [[13]] Such product models seek to establish a common computer based information structure to underly and integrate information in the building project. Some advocated techniques define systems which have many of the features of current GIS systems.[[14]] Others propose abstract models from which the data needs of application programs are deduced.[[15]] The proposals for such models may be seen as a recognition that neither existing computer or manual systems sufficiently meet user needs creating a shortfall in provision. 'The reality is that building designers already use a large number of informal product models, each specialized to a particular task or group of tasks in a particular domain';[[16]] but these may not become integrated at all except in the finished building. I have more enthusiasm for the approach outlined by Mugridge and Hosking in which they advocated an evolutionary approach to developing a common model, with data accumulating in the common repository through increasing use of linked applications.[[17]]

GIS tools have developed as applications surrounding a central database, and indicate how common models may evolve. New data can be inferred from existing by re-entry of the results of use of these tools into the database, which can then be analysed by further tools. GIS contain tools to calculate topological relationships from geometrical representation. The approach described as the Skull Object Space, in which semantic representation is derived interactively from geometric and topological representation, shows how such applications could be added progressively to enhance the overall description of the building.[18] GIS depend upon open and accessible databases. Most use mainstream commercial databases with custom links to graphical data. They can therefore take swift advantage of the extension of Relational DBMS (RDBMS), already offering a measure of data independence, towards object orientation, so increasing functionality to allow text, graphics, other objects and knowledge to become an integral part of their database system.[19] Such systems are changing towards managing information and not just data. Extension of the Structured Query Language (SQL) used in mainstream RDBMS for spatial database management has led to definition of the GeoView, which enables a joined perspective upon selected spatial and attribute data. SQL is currently being extended to incorporate the elements of object orientation. Such a union of attributes and graphics is only partly enabled in current 3D CAD systems.

5. Repeatability and Accuracy

At Westbury Homes, in broadcasting complete buildings and thousands of library components from region to region there were problems with change and version control which required special systems to be written outside CAD. In 3D CAD the nature of multi-user interactive operation has not been formalised.

Transaction management is seen as a pre-requisite for a useful GIS. These involve updating data over a long period of time, and thus are long-transactional. Management is required of change, of amendment of the developing data, and of the sequence of versions. Simultaneous alternative versions may need to be explored and so managed.[20] Various mechanisms for transaction management have been identified. Check-out control involves duplication of a complete dataset or subset, until change is completed and the original over-written with the amended duplicate. This is similar to drawing and document management systems which are external to the data which they manage. Version management enables a database to hold any number of versions of the whole database without replication of common data, but requires the mechanism to be incorporated within the DBMS. Some commercial GIS systems, such as Smallworld offer both object orientation and full version management.[**20**] Identification of the sequence of variants during amendment of data over time is also a pre-requisite to analysis of change.

Exploration of temporal GIS use has identified several requirements for time-stamping of data. Issues are raised about the potential lag between world time and database time. Time-stamping is suggested to mean both recording the time at which an event takes place and also the lifetime of an event, recording values for both 'time since', and 'time until' at the record level of each entity. Extensions to SQL to accommodate queries based upon operators such as 'when' and 'during' have also been identified as necessary.[21] Much research in GIS is focused on the area of error in data. It is common practice when entering data to record also the quality of that data, to better inform later users. Quality is categorised as repeatability of data capture, accuracy of capture, fineness of measurement, and precision of storage.[22]

Without clear and unambigous access to definitions of the quality with which models were composed, users demanded accuracy to the nearest millimetre, and no fractions, before they would accept work submitted by others. To quality might be added a need to record permissible tolerances forconstruction of new entities in 3D building models.

Traditional manual quantities taking-off relies upon drawings, expressed in a language of graphical conventions, intelligent interpretation of that language and the associated specification of works, and repeatable methods. The conventional graphical language is standardised, and so are the methods of measurement. Repeatability of output provides needed audit trails. Any trained user can check back and determine the extent of synchronisation of drawn information, specification, and quantities. If the contractor questions the take-off any trained surveyor can check it. This audit trail needs to be incorporated into 3D CAD modelling. Most 3D CAD proprietary software is optimised to generate primarily 3D views, and secondarily 2D conventional drawings, but not to promote accurate quantities. Westbury Homes were not enabled by the software used to marry separate resource or activity objects to the physical product objects being built on screen. Users were compelled to build complex product objects fragmented by different costs. The process required a close liaison between quantity surveyor (QS) and modeller, but compelled very high levels of knowledge of costs on the part of the modeller to avoid delay through iterative corrective passes from modeller to surveyor to achieve feedback. Amendment and re-use of the models became more complex due to the fragmentation of entities according to use of resources. Incorporation of the QS system within the 3D CAD system would empower the modeller and minimise the feedback cycle.

Within GIS software in general there is the ability to distinguish data by location, adjacency and context, due to the accessible and topological nature of the database. In buildings complications usually occur at the junctions between zones of construction and materials. The builder needs to understand the connectivity and adjacency of components and materials. These are implicit in drawing output, but would need to be made explicit within a 3D CAD information system. Use of GIS tools to distinguish data in these ways, would enable users to express the rules or conditions, under which the allocation of resources differ when applied to apparently similar components or products. Complexity of modelling could be significantly reduced. This would be a process similar to a quantity surveyor building up an analysis of costs from exploration of the finished building. The alternative, far more challenging, would be to allocate resources by modelling the construction sequence.

Westbury Homes needed to automate accurate quantities. The software used made this difficult. Although windows, doors, and other entities could be deducted automatically from gross areas of wall, floor, and roof, this facility was implemented in the software in an unalterable manner that provided difficult to use reports. They ended up with external systems to deduct openings and to adjust areas to produce net measurements, and users found it essential to model in such a way that the system could schedule each layer of a multi-layered construction accurately. Most systems encourage users to draw multi-layered constructions with a single CAD entity. Use of a single entity for multi-layered construction allows the easy iterative amendment of specification, and speeds the modelling process, but risks measurement errors at junctions. Ideally each skin, within the multi-layered construction, would be a separate object, capable of separate measurement. While most systems do allow a single cad entity to be defined for each skin of construction, each is required to be separately modelled, so lengthening the modelling task, and making amendment a challenge. Many systems speed the task of inserting and relocating openings with specific commands operating on a single CAD entity, which however fail when confronted with separate entities making up a multi-layered construction for which the relationship exists only in the mind of the user. Matching openings can be inserted in each entity, but take longer. Relocating multiple co-ordinated openings takes longer too. Software that checks for coincidence between opening and entity is normally written to deduct the opening from a single entity only to calculate net area. To use multiple CAD entities to express a single door or window opening seems a contradiction in logic. The simple modelling rules built into the black-box of current CAD software lack user control or sophistication. GIS systems offer greater control over the search criteria, and the rules and conditions that users may deploy to identify or relate entities.

It is difficult to choose one particular method of measurement that gives all users equal confidence in an audit trail that they can independantly reproduce, which leads from model to resulting quantities It may be more useful to allow users to choose the method of measurement they wish displayed when they want to check the quantities, as reported output, than to particularise on a specific conventional method built into the software. Such an approach would accord with the suggested interpretative mechanism for generating conventional drawings from a single building model. The software itself should promote complete accuracy in modelling the quantities actually used in the completed building. Resources, cutting, wastage, and temporary works are variables which ought however to be definable by the user, or modelled and controlled within the sequence of construction. Such definitions are possible in data analysis using GIS. Some quantities and costs are accurately measurable from a snapshot of the finished building, but others only with knowledge of the sequence used to deploy them.

6. Time, Motion and Value

Westbury Homes use single building models to co-ordinate three simultaneous requirements, cost schedules, construction drawings, and visualisation. The available CAD entities did not adequately support this output, so users produced very highly structured jigsaw models made up of clusters of small entities responding to each need. This is challenging to manage and amend. If any further needs had been added I believe that the modelling task would have become self-defeating. Spatial description of the building is limited to a snapshot of its finished physical form at one moment in time. This description simplifies but adequately represents real buildings for drawing and schedule output. These do not need to be assembled in a model using the same sequences and components that would be used in building upon site, yet may still enable design solutions to be explored in advance and so reduce wastage and delay on site. The risk is that temporary works are omitted, as is all the orchestration of construction.

While rendered images taken from 3D CAD building models have now become commonplace, they do not convey more than an impression of the finished building from a carefully chosen viewpoint. Sequences of such images, reproduced at 25 frames per second, give an animated tour of the model, but are still restricted to pre-selected paths. These may help the hard sell of a project, but yet not model either the experience conveyed by the actual building, or the sequence of construction. The modelling method and product would need to change to a more flexible and dynamic animation of alternative sequences of erection if it is to be used by builders to plan work-flow on site. There is in effect no reason why critical path analysis should not have three-dimensional photo-realistic representation.[23] There are at least two methods of balletic notation for graphically communicating movement and sequence.[24] Alternatively programs such as 3D Studio define specific path entities. An analysis of dynamic change as in the 3D Studio Keyframer combined with clash detection might serve to check construction constraints. Such approaches may be used to formalise codes for data entered within the model. New regulations for safe working practices in construction and later maintenance may require similar formalisation.

Time in the context of GIS has been categorised as: phenomena observed at different points in time, which relates the current production of snapshots of finished building states in 3D CAD modelling; programme, i.e. time for occurrence of specific events, which is not normally explicit in the single building model; and spatial modification over time, which could for example relate to changing patterns of use and occupancy of the finished building.[22] GIS mechanisms that enable version management may assist in modelling the process of change. 'Because changes occur over time, whenever an object is created or modified, versions of this object should be available to provide a temporal update process in the GIS'.[25] This may also support comparison of predicted with actual outcomes, serving to better inform future predictions.

At Westbury Homes a need was recognised for an organised system for making comparisons based upon historic data, and various prototype systems were introduced. The very limited codes available for identifying attributes within the CAD database caused great difficulty. Appropriate historic data extracted from previous building models or development versions of the current model can be used to set maximum and minimum quantitative constraints. During development of a design, and before all the detail is input, broad brush description of building elements can be rounded out with historic data to predict a complete outcome. Version management and analytical tools which identify trend would assist this process. These exist in current GIS Systems.

It is becoming increasingly necessary to convince those who commission buildings that the outcome will match their expectations. Modelling within virtual reality (VR) software allows the client to choose any viewpoint and examine it closely, to improve value management. Yet use of a single building model to generate conventional drawings, schedules of quantities, and to enable a virtual reality experience, creates potentially conflicting outcomes. A variety of specialised CAD entities are used to support accurate modelling in 3D CAD. Many of these entities require translation to a simpler triangular faceted mesh to enable the swift operation of virtual reality software, or animation software. Hierarchical classification of entities is required, based upon orientation and location, and zoning to enable distance based substitution of simpler representations. Accurate measurement, close-up depiction of construction, or sectional views of construction are difficult to invoke in VR.

VR entities and classification conflict with those optimised for conventional drawing output, accurate quantities and photo-realistic images. This necessarily creates multiple sub-models. The least useful means of creating and managing such sub-models is to create them all independantly. Translation from detailed to simplified forms is more desirable, and will continue to be required until VR technology can support much larger or more detailed models than are currently practicable. This is an area where 3D CAD building modelling appears to be in advance of GIS development, probably because the scale of VR model supported is so limited [8]

7. Translation to simplify or transfer data

At Westbury Homes other needs were satisfied by translation from the common building models, with consequent risk of lack of synchronisation. Such translation was necessary to produce simplified building images for use in landscape visualisation of complete sites, and to feed synchronising key data between site engineering and architectural CAD systems. The engineering CAD software did not accept negative coordinates and expressed height as an attribute, so preventing truly vertical surfaces. Translation was fraught. It was often easier to produce the simplified model separately, rather than to spend time enhancing poor output from the translation process. Duplicating data creates a data storage, as well as a management, overhead, which could only be minimised by holding all the datasets in a common database where replication can be identified and avoided, through version management. Translation was found to be necessary to either simplify data from one representation to another, or to enable as close a match as possible to be held in a different software application.

GIS software exists which enables analysis of the data spatially and by orientation to derive a new classification which would suit the special needs of VR. Tools exist for calculating and determining orientation and contiguity, the results of which can be fed back in to re-order and enhance the data to suit applications such as these. [22] Experience gained in GIS research still questions the value of fully automatic simplification of spatial data. 'Map generalisation is the process of reducing the amount of detail in a map so that the character or essence of the original features is retained at successively smaller scales.' Translation to achieve generalisation may always require manual intervention, but has already been shown to be capable of successfully recognising and building a hierarchy of meta-objects from detailed maps within pre-defined rules.[26] Data aggregation techniques used in conjunction with graphical and symbolic simplification serve to retain useful links to a common database.

Bitmap pictures of items may be substituted in GIS for graphics on demand or following pre-set user specification. Symbols or icons are needed and can be substituted for drawings when scale or grain of display makes realistic drawing over complex. These may not be satisfactorily generalised from more realistic depictions through automatic interpretation and must then be specifically drawn. On the other hand generalisation to user-defined interpretative rules can be used to automate useful drawings from realistic models.

Due to the lack of these tools, or where they embryonically exist, due to lack of satisfactory user-control, many current CAD systems require the user to draw multiple switchable views for every scale and degree of generalisation, whether icon or not, when many of these views could feasibly be generated from the form of the elements in the model. The synchronising single building model risks becoming the by-product of a variety of different depictions of components. Switchable views can be defined for deployment in a Virtual World as well. The danger of this approach is that by allowing the modeller to pre-define all the viewpoints shown they are coloured by the modellers expectations. It makes this switchable and substitutable model more of a hard-sell directorial approach, and of questionable use in confirming value to the building user in advance of building construction.

The systems used at Westbury Homes held out the promise of automatically generated interpretative drawings from the single coordinating model, but in practice these were found so severely limited that extensive recourse proved necessary to the electronic equivalent of typing correction fluid. In this process of correction and amendment links back to the generative model were broken, because updating drawings automatically caused the tedious corrections to be over-written and so lost.

It has been argued that 'a design system should automate the drawing production process to produce artefacts that will distribute information as a result of the design activity, and not serve as a primary design activity itself.'[27] Westbury sought to model template buildings, for later application to specific sites. These were therefore in the form of performance specifications. The draughting approach to building modelling offered by the 3D CAD interface limited concentration on development of the model itself. Users ended up drawing a specific entity at every point, in effect modelling a fully detailed building, which then needed to be translated or simplified, before re-modelling to meet other needs. Use of 2D draughting techniques to communicate 3D models takes time, over and above that of building the model. Using current generations of CAD the time taken in achieving 2D conventional views can throw away all the advantages of building a single model, leading to the conclusion that 3D modelling to produce construction drawings is a luxury, not justified in practice.

Given development of 'intelligent systems' and neural networks, it is possible for the interpretative approach to approach the usefulness of an intelligent drawing assistant. The switchable and substitutive approach relies upon the draughting skills of the user to make sense of the varying views, and in the current state of development of such software, the final drawing output also requires further modification to be buildable leading to greater abstraction from a single originating model. There are already sufficient problems in the process of appropriately simplifying reality to create a useful 3D computer model, for it to be retrograde to introduce further abstraction and obscuration by communicating it through a filter of 2D draughting conventions.

In GIS a distinction has already been made between interactive visual display of spatial data, and conventional graphical output in the form of new maps. [8] Most users of 3D building information systems are without interactive access, and therefore a major requirement is still the output of conventional drawings. The boundaries between interactive display of 3D building information and conventional drawing output therefore remain blurred. To alter this the process of cultural change needs to move beyond the design office to provide interactive access to those on site. Attention may then usefully be paid to the nature of interactive use of 3D building models, leaving the publication of drawing output to linked but separate systems.

8. Conclusion

Improvements in building project information systems, based upon 3D CAD models, would be made by tools which enabled users to:
1) Enter building descriptions into accessible databased inventories with 3D graphical display and manipulation of the spatial component of the data;
2) Link complementary applications to the descriptive inventory;
3) incorporate Change, Version Management and Time-stamping of data as an integral part of, and to manage the database;
4) Record and interrogate the quality and accuracy of data;
5) Calculate contiguity and adjacency from locational spatial data, and so assist the allocation of resources to entities;

6) Report linear and area measurement graphically according to user specification;
7) Explore the effects of alternative resource, cutting, wastage, and temporary works allocations to the spatial data;
8) Explore the sequence of assembly within user-defined constraints;
9) Set minimum and maximum constraints deduced from historic data within the database, to identify and report quantities and items which fall outside these bounds;
10) Generalise models within pre-defined parameters;
11) Capture images from the generalised models to use as icons or develop as symbols;
12) Control the degree of realism or generalisation of components of the building model within pre-defined constraints to 'interpret' the model to generate acceptable conventional drawings, or substituted icons or symbols appropriate to scale and view;
13) Model performance specification buildings to which the specific allocation of materials, components and resources may be added later, both as attributes and graphical expression, for 'what-if' exploration, and site-specific application.

Current provision of 3D CAD building models is not adequately meeting the needs of a common interface to an integrative method of binding together building information. GIS systems have developed further, faster, in relating graphical display to spatial information. Consequently they already provide a more integrated suite of tools which match the needs expressed above. Lacking adequate 3D modelling and display ability, they are not a satisfactory alternative to 3D CAD for building modelling, but are becoming more applicable, particularly in the field of facilities management, in which they are probably already superior.

While at Westbury Homes it took a few months to prototype and implement workable systems, it took much longer to gain the full acceptance and commitment of the staff to using them. Improvements in tools, in the ability for users to specify and define their own output, and in ease of use are essential for this time-lag between conception and use to be reduced. Single Building Model theories might begin to be applied in practice by users, if they had more effective and flexible control over the systems they use.

9 Endnotes

[1] Based on case study and survey of current CAD software.

[2] The sixth largest housebuilder in the UK. Now using Gable CAD for architecture, Moss CAD for site engineering.

10 Bibliography

[3] Eastman Charles M. The Evolution of CAD: Integrating Multiple Representations. Building and Environment. 1991. 26 (1) 17-23.
[4] Neil Allen. Westbury Homes IT Director, quoted in CADD, September 1991, p39.
[5] Based on survey of GIS software, use of GeoSQL & Idrisi, and evaluation of other GIS software.
[6] Goodchild MF, 1991 The Technological Setting of GIS. In Geographical Information Systems: principles and applications. Longmans.
[7] **Maguire DJ 1991 An Overview and Definition of GIS. in Maguire DJ, Goodchild MF, Rhind DW, (eds) Geographical Information Systems: Principles and Applications. Longman. London.**
[8] **Cassetari S, 1994 Visualisation and virtual reality: Prospects for GIS. In Green D, Rix**

D, Cadoux-Hudson J, (eds) Geographic Information 1994. Taylor & Francis.
[9] Björk B-C, 1992 A Unified Approach for Modelling Construction Information. Building and Environment 27 (2) 173-194.
[10] Goodchild M.F. Towards an enumeration and classification of GIS functions. IGIS Symposium: The Research Agenda. Ed. Aangeenbrug & Schiffman. 1988.
[11] Newell R.G, Theriault D.G. 1990. Is GIS just a combination of CAD and DBMS? Mapping Awareness 4 (3) 42-45.
[12] Svensson. K. 1991. Neutral Building Product Models: The KBS Model. Swedish National Board of Public Building.
[13] Ford S, Aouad G, Brandon P, Brown F, Child T, Cooper G, Kirkham J, Oxman R, Young B, 1994 The Object Orientated Modelling of Building Design Concepts. Building and Environment. 29 (4) 411-419.
[14] Zamanian MK, Fenves SJ, Gursoz EL, 1992. Representing Spatial Abstractions of COnstructed Facilities. Building and Environment. 27 (2) 221-230.
[15] Lakmazaheri S, Rasdorf WJ, 1992 An Artifact Modeling Approach for Developing Integrated Engineering Systems. Building and Environment. 27 (2) 209-220.
[16] Wright AJ, Lockley SR, Wiltshire TJ, 1992 Sharing Data between Application Programs in Building Design: Product Models and Object-Orientated Programming. Building and Environment. 27 (2) 163-171.
[17] Mugridge WB, Hosking JG, 1995 Towards a Lazy, Evolutionary Common Building Model. Building and Environment. 30 (1) 99-114.
[18] De La Garza JM, Oralkan GA, 1992 An Object Space Framework for Design/ Construction Integration. Building and Environment. 27 (2) 243-255.
[19] Howells I 1994, Objects in the real world - evolution not revolution. In Green D, Rix D, Cadoux-Hudson J, Geographic Information 1994, Taylor & Francis.
[20] Newell RG, 1994 The Why and How of the Long Transaction. In: Green D, Rix D, Cadoux-Hudson J, (eds) Geographic Information 1994, Taylor & Francis.
[21] Kemp Z, Kowalczyk A 1994 Incorporating the temporal dimension in a GIS. In: Worboys MF (ed) Innovations in GIS 1. Taylor & Francis.
[22] Laurini R, Thompson D, 1992 Fundamentals of Spatial Information Systems, Academic Press.
[23] Retik A, Warszawski A, Banai A, 1990 The Use of Computer Graphics as a Scheduling Tool. Building and Environment. 25 (2) 133-142.
[24] Tufte, ER 1988, Envisioning Information. Graphics Press.USA.
[25] Wachowicz M, Healey RG, 1993 Towards temporality in GIS. In: Worboys MF, (ed) Innovations in GIS 1. Taylor & Francis. 1994.
[26] Robinson GJ, Lee F, 1993 An automated generalisation system for large scale topographic maps. In: Worboys MF (ed) Innovations in GIS 1. Taylor & Francis. 1994.
[27] Myers L, Snyder J, Chirica L, 1992 Database Usage in a Knowledgebase Environment for Building Design. Building and Environment. 27 (2) 231-241.