



STUDY REPORT

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A BUILDING DATA MODEL FOR INTEGRATION

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Building Research Levy, and the Foundation for
Research, Science and Technology from the
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PREFACE

The building industry is now actively using information technology in all phases of construction. Some of the major ongoing problems identified in the building process are due to the continuing fragmentation of building-project information. This highlights the need for representation and storage of this information in a computer in such a way as to allow building professionals to use a common database containing information about the building they are working on. This is the concept of computer-integrated construction. The common database avoids duplication of information, aiding efficiency and reducing errors. The process of achieving integration has been acknowledged widely to require the development of data models. The data models 'represent' parts of the building and their attributes, and will enable 'human-readable' concepts to be implemented with computer representations. Most of the interpretation knowledge will be encoded in the models, something that is lacking in the data models used in existing computer applications.

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This report is an introduction to the concept of computer-integrated construction for people in the building industry who are likely to use information stored in computers, for example, designers, architects, engineers, and quantity surveyors.

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ABSTRACT

This report describes the initial development of a building data model as a first step on the way towards achieving computer-integrated construction. The concept of integrated construction implies data models for all phases of a building's life-cycle. The present study has been focused onto light timber-framed residential houses, looking at structural components at the late design stage. This scope fits the past computerisation work undertaken by BRANZ. The report describes some current modelling work, reuses other models, and refers to the STEP international standard. The report is a commentary, combining other ideas with some ideas from our own study, to develop an initial data model. At this stage, there is no emphasis on any computer implementation of this data model; this will follow.

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1 Introduction

1.1 The Building Data Model (BDM)

The building industry is actively using information technology in all phases of construction for a wide range of tasks. Some of the problems in the building process are due to the general dispersion of building-project information amongst project participants. A great number of professionals are involved in a building project. These professionals, usually from different organisations, have to work together and need to share the building-project information.

At present, each individual will independently create building-project information appropriate to his/her discipline (architects, engineers, building officials) for use in architectural design, engineering design, or checking codes and standards. Thus, at various times, there could be a number of versions of building-project information on one particular building. This creates the risk of misunderstandings and inconsistencies as well as being time-consuming due to duplication of effort. Clearly, there is a need for these professionals to use a common database containing building-project information about the building they are working on. An obvious way of doing this is to set up computer databases.

In Finland, a national co-operative study, the RATAS project (Bjork, 1991) was undertaken to address the issue of the integration of computer systems for building design and construction. The most important conclusion arising from the RATAS project is that in order to achieve industry-wide use of computer-integrated construction, the information used in the design, construction, and maintenance processes must be standardised, and one way to achieve this is by the use of a building data model.

Characteristics of a Building Data Model

Bjork (1989) outlines the characteristics that a building data model must have:

- Any BDM must be comprehensive. It must be capable of containing all kinds of building data, which currently are contained in briefs, drawings, standard details, specifications, bills of quantities, calculation program outputs, etc. Drawings and other documents can be produced from the model when they are needed.
- The BDM should not dictate the format and contents of the output documents.
- The BDM must not contain redundant data. Each item of information is only defined once in the model. Nowadays, the same information can be contained in many documents, and revision done in one has to be made in all other documents. This will not happen in the model.

- Finally, the BDM should not be dependent on specific software and hardware systems.

An outline of the types of information and data that will be extracted from a BDM database is illustrated in Figure 1.

The term 'building data model' (BDM), is our alternative to the term 'building product model' (BPM), which is commonly used in the research community. The word product (implying modelling over an object's life-cycle) would cause confusion within the building industry, hence 'BDM' is used, except where definitions from the research community are quoted (in Section 2.1).

1.2 General Communication Needs in the Building Industry

There has been enough research on the causes of poor quality in finished buildings to show that one major cause is poor communication practices. The latest Australasian analysis of the building industry (ACT, 1990) illustrates this. Two communication problems were identified: unclear or missing information, and lack of coordination in design. The other major cause of poor building quality was lack of care on the construction site.

The most effective way of influencing quality open to those who produce the 'instructions to build' is to produce complete and timely project information.

Methodologies have been worked out to coordinate information in the documentation of a proposed building, such as the Common Arrangement of Work Sections (CAWS) (CPI, 1987), advocated by the Association for Coordinated Building Information in New Zealand (ACBINZ). These are based around current project documentation methodologies, and do not specifically address computer use.

The Use of Computer-aided Tools in the Building Industry

Computers are now being used more and more in the industry. Programs exist for all tasks in a building's lifetime: early design, design analysis and evaluation, developed design, working drawing production and visual presentations of the design to the client, costing at various levels of detail, bill of quantities production, specifications, regulation compliance, permit application, land and site information, and facility management databases (Price, 1990).

Current Attempts at Integration and Some Problems with these Techniques

Currently, sharing of information can occur between closely linked tasks such as building production drawings and bill of quantities creation. Such sharing is ad hoc in that there are two models (or views) of the information, and an interface must be developed as a

means of interpretation of each information model. It is generally the case that each model of information is local and not readily available for other applications to use. The user of current software tools is usually caught up in the processes of transferring and checking transmitted data - new, unwanted tasks that, with the ever increasing volumes and types of information flowing, will soon get out of hand. This is likely to form a major barrier to full utilisation and integration of computer-aided tools.

Integration of information databases within the wider context of the entire building life-cycle is a simple vision that has been around since early use of computers. But the idea has not yet been realised in practice because:

- General computer usage over most of the building design life has just arrived. Previous computer applications were remote islands of automation, each with its own data input and output tasks.
- Today's commercial computer technologies have just become adequate to handle complex information models, at a reasonable cost.
- The huge volume of data needed to be input into an 'all-inclusive' design is prohibitive. This is due to the large effort required to transfer information generated elsewhere or to recall typical forms of data that suit the requirements.
- Lack of understanding of the common semantics of building models is widespread. Semantics here means the definition of building objects, rules of composition, and relationships necessary for their manipulation and analysis. Even though there are written standards (such as graphic images, schedule phraseology, and the development of a building terminology thesaurus) these are separate views on building objects which are database representations of the physical parts of the building. These existing standards convey little semantic information to enable sharing of data amongst different design discipline tasks. More thought needs to be put into standard building models that allow multiple applications to work from the same input data in a consistent manner (Bjork, 1989).
- Because much of design deals with geometry and therefore is recorded geometrically, there is the general impression that geometry-based systems provide full support for the engineering design process. Geometry is, however only part of the process (usually the presentation of the developed design). Attempts to extend purely geometric representations to incorporate other types of design information 'decorate' the geometry (i.e., add additional meaning), and are limited in their utility (Turner, 1989).
- Computer program developers' lack of attention to existing practices and the roles of the participants in the building design process has hindered progress.
- Architectural design methodologies are often 'black box'; there are no standard methodologies.

1.3 Global Strategic Issues in the Development of the BDM

BDM development work must come before any specific 'de facto' standards are developed by vendors of computer-aided tools. BDM work must contribute to future standards that are accepted by the marketplace. Separate vendor-specific standards will not work for computer-integrated construction which concerns everybody. Hence there is an imperative to continue the BDM development initiative, and present the results and benefits.

The built environment is such a diverse universe of objects, tasks and peoples' views and methodologies that a major issue is how extensive a practical BDM can be. What information can be contained in the BDM database? There will be much debate as to the degree of inclusion of values able to be derived from other entities already in the database.

Geometric shape and location data are vital to the building industry. Any BDM prototype without the ability to incorporate geometry is limited in its representational power and application to tasks within the building industry. The work of developing general geometry standards is under way, both by commercial CAD companies and by the developers of the STEP standard (see Section 2.1). The literature pertaining to the development of geometric models within the STEP standard (STEP, 1991a) provides an overview of current standard models of geometry. The comprehensive modelling of artefacts in the built environment is an enormous task, and any current modelling can only be focused on a small subset of objects. Hence the modelling work for a specific area such as the building industry, first needs to focus on the fundamental objects and their relationships, and then to use standard models for geometry as a means of representing the objects.

Architectural design is practised by many in a black-box way (it is an art), and there are no standard design methodologies. Any attempt at organising and structuring design methods at the early design stage will simply be met with resistance. The BDM is a means towards better integration of information produced in a building's life-cycle. It has little to do with actual design task automation in an 'all-encompassing design integration system'. The BDM does not pose a threat to design freedom (unless the BDM is restricted to small subsets of the built environment).

2 Existing Data Models

2.1 Concepts, Information Architecture and the Models Behind the STEP Standard

The International Standards Organization (ISO) has published the first part of the STEP standard (STEP, 1991a). STEP (STandard for the Exchange of Product Data) will be the first truly international standard for computer-aided design/draughting data. Past standards such as IGES (Initial Graphics Exchange Standard) were national activities. The definition of the standard is based on the development of data and languages for manufactured products.

The term 'product models' is the accepted term within the STEP community for data that can describe an object over its entire life-cycle from design and manufacture through to use and disposal. The word 'product' is appropriate as the majority of the effort within the community is in the parts manufacturing industries (particularly for military use). Other industries such as building and construction can equally benefit from such a standard, but have not yet entered into BDM development activity with any serious commitment.

The STEP standard provides a neutral mechanism capable of describing product data throughout the life-cycle of a product (in our case a building), independent from any particular computer-aided system. The nature of this description makes it suitable not only for neutral file exchange, but also as a basis for implementing and sharing product databases and archiving.

A neutral representation of product model data is provided in the form of a set of modular 'integrated resources' that together support a complete and unambiguous definition of an object. This information model is split into two groups of model classes. The first group of three classes is specific to 'some area of interest' or 'an industry' (termed an application). The remaining classes are the resource sets: they are generic and context-independent. The resource sets are used by the application specific models. A resource set is structured to reflect the fact that some information is common to more than one area of product data. Within STEP, this is referred to as the integrated product information model (IPIM): see Figure 2. The current activity within STEP is the organisation of the application-specific models and resource sets. The way future models are developed and how they will fit together (without duplication of data) are under consideration.

Application-specific models are called 'application protocols'. They incorporate the basic information required for a particular area of interest, and the basic STEP entities used. The information part of an application protocol goes beyond current systems (such as IGES) that assume a database of entities, without describing how these are used. In STEP, the way entities are used is described in the form of data structure constraints,

using the EXPRESS information language (STEP, 1991b).

The terms used in the STEP standard are defined in the document 'Part 1: Overview and Fundamental Principles' (STEP, 1991a). This describes such terms as application protocols, and reference models which are parts of the general methodology to build product models (data models) and to use existing resource sets. The basic types of information for a data model are defined (assemblies of objects, their classification, location, shape, and connectivity).

These application protocols, reference models, etc., are formal documents required in the standardisation process in addition to the important validation of data translation programs that try to adhere to the standard. Their development requires thorough debate with democratic canvassing of users opinions.

The STEP standard will evolve to provide data translation mechanisms with four levels of data exchange capability. The first level is a 'flat file' exchange, which is similar in concept and content to existing exchange standards such as IGES. The second level uses a database as a temporary working form. Next are the permanent databases, used by a number of applications. The most developed stage of STEP translation mechanisms will be the knowledge base with an object-oriented database where constraints and behaviour of the modelled objects are stored.

Modelling Notations

It is important that a common notation is used while creating information models. Two notations that have been accepted within the STEP activities are NIAM diagrams (Turner, 1991) and the EXPRESS language (STEP, 1991b). NIAM is an object-based conceptual notation, describing binary relationships between real and abstract objects. It does not include rules (logic statements). However, NIAM models can be translated to an EXPRESS statement, where rules can be added.

EXPRESS is now the formal information modelling language of STEP activities and documentation. An EXPRESS information model defines the 'what' while the 'how' can be implemented on a computer in many ways.

EXPRESS borrows language constructs from a number of information technologies: database query languages, object-oriented languages, procedural languages.

Table 1 shows a sampling of EXPRESS code which is taken from STEP Part 101, a resource application protocol that describes data for general draughting (drawings).

Table 1: A sampling of EXPRESS code.

```
SCHEMA general_draughting_resource_schema;
```

```
ASSUME (generic_product_data_model_schema,  
        product_shape_interface_schema,  
        tolerance_schema,  
        ipim_presentation_schema,  
        ipim_pscm_schema,  
        security_and_approval_schema);
```

```
-----  
TYPE drawing_type = SELECT  
    (mechanical_drawing_type,  
     architectural_drawing_type,  
     non_standard_drawing_type);  
-----
```

```
ENTITY drawing;  
    identifier      : drawing number;  
    creator         : person_organisation; --GEDM  
    custodian       : person_organisation; --GEDM  
    latest_version  : drawing_revision;  
    category        : drawing_type;  
UNIQUE  
    UR1: identifier, creator;  
END_ENTITY;
```

```
-----  
ENTITY sheet_size_requirement  
SUPERTYPE OF (ONEOF(standard_sheet_size,  
                    non_standard_sheet_size))  
SUBTYPE OF (drawing_requirement);  
    horizontal_size : length_measure; -- GPDM  
    vertical_size   : length_measure; -- GPDM  
WHERE  
    WR1: (horizontal_size > 0.0) AND (vertical_size > 0.0);  
END_ENTITY;
```


This example in Table 1 shows some EXPRESS language constructs to:

- **refer to existing models:** here using the ASSUME statement,
- **outline types of objects possible:** as in possible drawings, using the TYPE statement,
- **create an object:** using the ENTITY statement, a drawing is defined as having five attributes, two of which together define a unique entity, i.e., no other drawing in the database can have similar values in these two attributes.

2.2 Architecture, Engineering, and Construction Information Schemes

Traditional Classification Schemes

Within the building industry worldwide many text-based classification methods have been proposed for describing the objects in the built environment. Two prominent schemes are CI/SfB (CIB, 1986) and the more recent Common Arrangement of Work Sections - CAWS (CPI, 1987).

As well as these general classification methods, some manufacturing sectors within the building industry have been able to standardise their products. For example, the New Zealand Concrete Masonry Manual (NZCMA, 1990) gives a system to classify concrete blocks. CADD users who wish to deal with such products in detail would use these schemes. These product-specific schemes do not conflict with the general schemes, as product classification is more detailed.

Each major discipline in the construction process - architecture, and engineering, specification, estimating, construction management, subcontracting, facilities management - tends to have a different perspective on the building life-cycle and construction information. These individual perspectives impact upon the means of storing and using information. Each discipline also places different emphasis upon the context of building components.

- **Designer:** the functional context, often not directly involved in planning and construction phasing. Details such as actual construction steps are often left out.
- **Specifier:** materials and methods of construction.
- **Quantity surveyor:** dimensions and numbers for cost estimation.
- **Construction manager:** scheduling work, supply of resources/materials.

- **Contractor:** assembly, application of material.

Classification schemes use terms such as 'component' and 'element'. These and other related terms are defined as:

- **Building material:** a particular substance used in the construction of the various building components.
- **Component:** a building item that can be identified and quantified as part of the building. A subset of a building element.
- **Building element:** a part of a building that is made up of one or more components that provide a specific function within the building.
- **Trade or craft:** a labour group that normally provides for the construction and/or installation of various building components.
- **Attribute:** descriptive data associated with a component. Data on function, material, installation, location, dimensioning, tolerances, and quantities.

A building product model is a modelling system that treats information in a more generalised way. As such, it is able to treat classification methods as specific views according to needs.

The first task of the project was the collection of outline information into 'data scrap-books' for each of the main building elements, in what could be called a 'condensation' of attributes, descriptions, and classifications of objects. Text definitions were collected from several building industry definition glossaries. Detailed study has been confined to several references.

The Building Systems Integration Handbook

The authors of the 'Building Systems Integration Handbook' (Rush, 1986) developed a conceptual modelling notation for the complex integration of systems in modern commercial and industrial building design. The intent of this is to create a theory and symbolic vocabulary that will allow designers to discuss integration strategies before and after choosing the specific physical systems in a modern complex building. The purpose of an integration diagram is to allow the designer to investigate and record the level of connection between any two building components or subsystems, which can provide a notation with which to attempt optimisation of integrated designs. This method of looking at the way components connect can be applied to residential buildings.

The theory postulates that four systems are sufficient to completely describe a building (in terms of the integration of physical objects).

- structure,
- enclosure,
- mechanical, and
- interior.

These four are combined together in a tetrahedron that incorporates all of the two-system and three-system combinations inherent in modern building design. These systems and their functional aspects are placed in the data model summary (Section 3.5). Five levels of physical object connectivity are defined: remote, touching, connected, meshed, and unified. A building is a complex arrangement of many objects; hence a notation to describe the connections between objects is useful in describing buildings.

This diagrammatic notation represents spatial connectivity information of building systems that notations such as NIAM do not provide. The notation should be considered by researchers as another analysis tool at the early modelling stage of building data model development. Figure 12 uses this notation to show the overall building element (here meaning a major part, i.e., the roof) interconnections of a house.

2.3 Some Work Worldwide in AEC/Building Systems Modelling and Integration

The study of various organisations' work in the area of computer-integrated construction has been conducted with an emphasis on how each modelling notation or language can communicate ideas to interested parties. For the development of data models, it is the author's desire that organisations make public detailed model descriptions (or structure templates) rather than overviews of database structures for presentations, etc. There is much to be learnt through the detailed examination of a database. The detailed object classes, relationships, and attributes can be reused and refined. Overviews of databases usually do not provide a lot of new understanding on a subject; they just reflect common knowledge of subject areas. This is where the information modelling notations such as NIAM (Nijssen 1989, Turner 1991) diagrams can be put to use in the description of the semantics of a database, to aid in the communication of, and debate on the information exchanged. A lot of useful debate (leading to standardised data structures) can occur with clear descriptions (usually graphical) of database structure.

Several organisations around the world have comprehensive long-term computer integration projects. They cover work to do with the application of basic technologies (CIFE, 1990) more advanced work to do with building intelligent design assistance (Pohl et al., 1989) and proprietary advanced CAD systems (such as Sonata, Master Architect, IBM's AEC Series, and Timberline). Numerous university projects (e.g., the GDS CAD System)

have tackled integration of basic 2D/3D geometry since the 1970s. These are examples of successful integration attempts. Sometimes the structure of the objects within a CAD system is published. These CAD systems usually have a geometric objects database on which advanced CAD applications can be built. Integration can occur using this localised data scheme. However, little standardisation of data structure has occurred, and there is a diversity of applications. Wider, 'true' integration requires formal descriptions of data structures, and databases and transfer mechanisms that can store and process the data.

The development of information technologies associated with computer-integrated construction has matured. Although there are still many programming challenges to be met in encoding building knowledge, there needs to be emphasis on the ways to share data models that represent real-world objects. Most organisations which have done past integration work are moving into the 'product data' movement to standardise data models in a particular domain of interest.

AEC Modelling Undertaken in Association with the STEP Standard

The IGES/PDES Organisation (IPO) has a comprehensive mechanism of incorporation of new models into the STEP standard. Currently an architecture, engineering, construction (AEC) subcommittee of IPO is developing information models that define their universes of interest. The actual work of defining BDMs is a small part of the wide-ranging AEC work.

These contribute to the core of STEP, and are also serving as the starting point to develop application protocols: the requirements, models, tests, and documentation that define how to use the pool of objects in the proposed STEP standard to exchange information for specific applications.

Warthen (Warthen, 1990), refers to the major modelling work associated with STEP in the broad fields of architecture, engineering, and construction. A few of the models are building-related, yet they are the first examples of industry-specific STEP models. Each model has a defined scope, and they illustrate the integration of STEP application protocols and resources. They are collections of systems composed of parts, attributes, etc. The U.S. organisation NIST is involved in a number of these projects (NIST, 1991). Work has been done in the following areas:

- IGES 3D piping protocol
- Ship structures,
- Distributed systems,
- Building design and other building-specific models,
- Facilities management,
- Functional aspects of distribution systems,

- Libraries for AEC distribution systems.

Australian Work

The Australian contribution to STEP work has included a submission on an architectural draughting subset of the IGES entities, and one of the application protocols for draughting in the STEP standard. The application protocol discusses how to use STEP geometric objects in drawings.

The recent Australian interest in the process of standardisation has arisen through recent experiences with large multi-disciplinary projects where integration of engineering and architectural design information was attempted. A focus group called BET - Building, Environment, and Technology (BET, 1991) - was formed in 1988 to develop a standard working environment for multi-discipline teams to work together and ensure portability of data. They saw a need for a framework within which users of any CAD system could confidently construct project databases, whether simple or complex, that can include all stages of design. The framework has two essential components:

- A set of naming guidelines ordered in an appropriate way for AEC projects.
- A general mechanism to decide when and how to divide the database. This framework is independent of any CAD system implementation.

The group is looking toward the STEP standard's architecture as fulfilling its requirements.

The CSIRO Division of Building, Construction, and Engineering is undertaking a building product modelling project (Leslie, 1992). They are taking a building project wide view, looking at the design decision-making process for simple elements such as the door schedule. They are emphasising changes to an information database during the project design process.

The RATAS Project

The Finnish research organisation VTT, with major support from its nation's building industry, has developed one of the most complex building product data models, RATAS (Bjork, 1989, 1990, 1991; VTT, 1992). This has resulted from several years work with industry, in the definition of information needs within the building design process. VTT has applied recent commercially available software tools to the implementation of its models.

The database structure has been tested with several case studies, the latest being a two-storey office building. With the most recent extensions to the models, the database complexity is hinted at by the counting of 50 object classes, some 1500 object instances

(or actual occurrences of an object type, within a working database) and about 500 inter-object relationships (such as connectivity). The object classes are grouped into: site element, foundation, load-bearing frame, building envelope, and room and interior elements for the typical office.

The RATAS model is based upon the common building level hierarchy (system - subsystem - part) of real objects in the context of commercial multi-storey buildings. The object relationships that form this structure are: is-a, part-of, and connected-to. 'Part-of' is used to separate objects into their components (mostly between objects in different RATAS levels). 'Connected-to' provides other meaningful relationships, generally on the same level.

The RATAS project has demonstrated the benefits of building data models through a series of prototypes. Each prototype makes use of available software technologies. Relational databases, hypertext, and a CAD system have been used to implement and view the database.

This comprehensive data model has not been translated into English. It is viewed by the Finnish building industry as an asset in the international marketplace. A previous version of the RATAS building data model was available in the form of the relational database table structure. The researchers are currently contributing to the STEP standard.

New Zealand Work

Amor (Amor, 1991) developed a common building model, primarily for the representation of building physics data such as thermal analysis. This was developed after the analysis of 26 CADD and building simulation packages. The data models within three thermal design packages available in the Unix computing environment have been integrated. Amor's model is implemented in a frames system written in Prolog. The common building data model stores the common data elements of the various thermal analysis systems. As well as the neutral or common building database, mappings are created that enable the data in the common building database to be passed to each of the three design packages.

The understanding of the data structure of these databases requires reading a file containing a list of classes, slots (place-holders), and facets (object type and attributes) inherent in the frames data model. In a frames system, the data structure is built upon the slot. Each slot has a facet which here includes: a-kind-of, values, world-values, types, constraints, units, defaults, descriptions. This is all in a one-dimensional list of classes and slots, which makes it hard for people to read, and hence to evaluate the data structure. The report (Amor, 1991) provides an appendix which lists objects with their data and attributes.

BRANZ and the University of Auckland Computer Science Department have recently completed a five-year research programme (Hosking et al., 1991a). During this time a

number of knowledge-based systems have been developed, centred around building codes for light timber-framed buildings: Damp, Firecode, Wallbrace, Adhesive, Subfloorbrace, Roofbrace, and Thermal Designer. Most of these have encoded parts of the ALF manual (Bassett, 1990) and NZS 3604:1984 'Code of Practice for Light Timber-framed Buildings not Requiring Specific Design'. Hence there is available code and diagrams of the classifications of building objects and abstractions. In our experience, it has been at times quite difficult to abstract and encode the interactions of objects within a building. Detailed study of the NZS 3604 code will separate the simple classification of objects from the abstract concepts. These abstract concepts provide the contribution to the data model structure.

With regard to the development of data models, these experiences strongly suggest that any collation of data and information via the study of text references must occur in unison with actual computerisation tasks. A BRANZ project integrating ThermalDesigner and Wallbrace applications will bring forth new ideas on how to represent a house's objects.

A Sample of Worldwide Work on Building Data Models

Researchers involved with the development of data models for computer-integrated construction acknowledge that the development of sophisticated data models has just begun. It is vital that comprehensive modelling can be achieved and demonstration databases be built which demonstrate practical integrated tasks.

BRANZ can contribute here with our demonstration of a data model and database, and the general methodology of describing data models for the purpose of developing computer-integrated construction databases. Figure 3 is a sample of worldwide work on computerising building information - it refers to work that has influenced this current work. Models from other activities have not been available yet.

3 A Building Data Model for New Zealand Residential Buildings

3.1 General Data Modelling

The data modelling work undertaken in this project is the modelling of information within a selected domain (light timber-framed house-structure).

The term 'data model' is the chosen phrase for the abstract representation of an area of interest. Abstraction is the process of picking only those properties that are relevant to the task in hand. Perhaps the term 'information modelling' or 'conceptual modelling' would be more appropriate, as we are abstracting properties and classifications of objects, trying to capture the meaning (semantics) of our area of interest. The term 'data model' should be taken as including all these. The word 'data' indicates that a database will be created from the model.

The initial data model is separate from implementation in any information technology such as a programming language or a database implementation. What is being developed is an information structure that describes a subject area, leading towards a database specification that can store a wide variety of information for tasks within our area of interest.

The data model development methodologies used in our work follow those laid down in the STEP standard (STEP, 1990a, 1990b, 1990c, 1990d, 1991a), and Geilingh (1988).

3.2 BRANZ Methodology in BDM Development

BRANZ has extensive interaction with the building industry. Consultation with design domain experts is vital to BDM development. Extensive communication and co-operation will occur with Auckland and Victoria Universities, and internationally with those involved directly with STEP.

The development of a description of residential buildings as a basis for the BRANZ BDM involves:

- Reviewing overseas models, their structure and the modelling issues they address and/or raise.
- Gathering and reusing models of information from other research projects, such as design evaluation, simulation data, basic geometric descriptions, and the initial

attempts at data modelling of buildings (the artefacts and the processes within the life-cycle).

- Adopting a common modelling terminology: NIAM which is graphical, and is similar to, but more sophisticated than, entity/relational modelling of data.
- Descriptive modelling is approached from two directions:
 - Top-down: from the general to the specific. The built environment is classified, for example, into project type, building type, tasks, and participants.
 - Bottom-up: using existing models of areas where available from work such as the STEP modelling (called application protocols).

As the BDM develops, it is necessary to demonstrate its use. There are many choices for the prototype: for example, what sector of the general building industry; what tasks to choose.

Demonstration prototypes have to be produced to show the benefits of the modelling work. Our long-term plan is to combine an object-oriented database/programming language with some graphic interface. Object-oriented databases provide data manipulation features necessary for CADD applications: an object class hierarchy storage, very high-speed data retrieval, data recovery, transactions, versions of data, and database queries.

These tasks require a number of person-years effort. The work undertaken in this report is the first step in the development of the basic information models.

Methodology: Analysis and Design

The basic methodology to develop an information model starts with the identification of the correct scope for the modelling activity. The processes that are to be integrated are outlined. A 'universe of discourse' (or problem domain) is established, that sets out the objects and tasks to be modelled. A well-defined focus for the modelling is necessary, as the information and the various abstract computer data models have endless scope. The modelling process is:

- **Define what objects to model.** The choice to model timber-framed houses was taken because houses are currently the major activity in the building industry; they have relatively simple structure, and in past research, BRANZ has undertaken the computerisation of codes of practice related to houses.
- **Define what information processes to model.** The demonstration of the use of building data models (called building product models elsewhere) to achieve computer-integrated construction requires as large a collection of processes over the life-time of a building as possible. Resources limit us to focus on a few tasks (late design representation and code compliance checking, where objects are well-defined).

- **Use existing standard models.** The use of commonly agreed data models is a vital component to computer-integrated construction, as initiated by the STEP standard.

The methodology for building the data model comes from the STEP community (STEP, 1989b). The main emphasis is building upon existing basic data models (Section 3.4) and developing an 'information architecture'. There are a number of analysis and design techniques in the object-oriented programming field (Vilot, 1990) that will be applied as the model is refined and implemented on a computer.

3.3 Scope of the Data Model

References on New Zealand Light Timber-framed Residential Building Construction

There is almost an oversupply of descriptions of house construction available in the literature. A considerable part of the initial work was the collection of 86 references to timber-framed residential building and building components in general.

The references were grouped as:

1. **Design solutions:** style, general or specific solutions for building systems or elements, manufacturers' catalogues.
2. **Presentation systems:** classification and coding systems (CAWS, CI/SfB, bill of quantities phraseology), glossaries, drawing techniques, architectural analyses, specifications.
3. **Principles:** standards, principles of design, building controls, checklists.

A few excellent references illustrate the daunting amount of information involved in the building industry. These references are 'Principles of Elemental Design' (Rich, 1982), the annual volumes of 'Specification 19XX' (Sage, 1987), and the NBA Commodity Files (NBA, 1975). Computer-integrated construction cannot occur without some accepted information model that treats all types of information as equal (not just geometry, etc.).

The processes used for constructing houses are different from those used for other building types and other manufactured items in other industries. These often have complex structures that require detailed, specific design. Well over 80 % of New Zealand houses do not need specific design: the builder follows common practice in the construction of house elements. The New Zealand Standard NZS 3604:1990 is the major guide to construction of the framework of a house which will resist the forces imposed upon it and remain

weathertight. It is a collection of tables and rules for sizing elements, connection methods, choice of building subsystems, and proximity requirements for the correct resistance and distribution of loads within the house.

The builder follows what instructions-to-build that are available - plan drawings, specifications, sketches. The building materials are purchased from an estimate of quantities of material made by the plan draughter or a quantity surveyor, but usually the builder. Generally many specific arrangements of house components (such as the soffit layout) are not specified, and the builder uses his or her own solution, or uses a product-specific system. Guidance on good house construction techniques is available to the architect, draughter, and builder, in a wide range of publications. The processes for the checking of compliance to standards involve checking at the construction consent stage and regular inspection of houses under construction. The process has been improved to provide, amongst other aims, a more uniform application of standards within the building industry.

The main emphasis here will be on modelling physical object assemblies of concern for people, and modelling procedures for instructing builders. This is a restriction to the late design stage of the life-cycle wide scope of 'product models'. The integration of life-cycle information is important, so the extension of the model to incorporate other life-cycle stages will be required. This should happen with BRANZ and Auckland University collaboration on early design systems. The ability to integrate these separate life-cycle stages of timber housing will be a research challenge.

This model focuses on a structural fabric model of the basic framing objects: the basic elements, assemblies, and their inter-relationships. Particular components such as doors, windows, stairs, plumbing (and other distribution systems) will not be modelled at this time. We are concentrating on the information requirements of NZS 3604 and other frame structure descriptions. However, where an object interfaces with the frame (e.g., window surrounding objects within the stud wall) they will be noted.

Figure 4 represents the basic structural components of a house modelled here.

Our model focuses on the study of information requirements of NZS 3604:1990, which provides a well-defined scope of objects to model. One of the main reasons for referring to this code is our past work with knowledge-based systems (Hosking et al., 1991a). Many reference books on buildings have been examined, but the basic structure of our model is based upon the data and information inherent in the code, but only includes part of the code.

Section 3.4 places our model in a context with existing models: what will be/will not be in the model, and how it fits into the overall picture of computer-integrated construction over the life-cycle of a building.

A useful set of objects for the life-cycle of a house would include the following:

- common timber construction techniques: external and internal walls, floors, roofs
- cladding: windows, doors, exterior walls, roofing
- distribution systems: electrical wiring, home automation systems, plumbing, communications
- common views of these objects, such as drawings and specifications.

Intertwined within these objects are relationships considering area, volume, and connectivity. The data models for these objects are currently under development. At this stage the model consists of the basic objects and a systems hierarchy.

The modelling work has focused on 'real-world objects'. As the model develops and is refined, it will incorporate views of light timber-framed houses such as house plans and classification systems for simple specifications. To do this, the STEP standard will be referred to. Useful parts of STEP (STEP, 1991a) will be two that refer to draughting (lines, etc. on plans).

3.4 Fundamental Models

The model for New Zealand light timber-framed houses starts by reusing existing data models. Reuse of models is the essence of the STEP standard that is the accumulation of nearly two decades of expertise in computer-aided design.

The following model documents form the basis of the data model presented here:

- AEC Building Systems Model (STEP, 1990a)
- Building Structural Systems Model (STEP, 1990b)
- Spatial Systems Model (STEP, 1989a)
- Building Enclosure Systems Model (STEP, 1990c)
- Building Structural Space Frame Model (STEP, 1990d)

These documents are not part of the official STEP standard, which will come out in 1993 in the form of a dozen parts (STEP, 1991a). Where the model has been fully developed and approved by the ISO (International Standards Organization), it is given an

ISO number. Models at earlier stages of development and approval, such as those listed above, are still referred to by the STEP AEC committee document number.

A start towards the creation of a building data model is made here. These are basic, fundamental systems that are applicable to all architecture and engineering systems. Descriptions like geometry are placed in their correct perspective, equally ranked with such items as attributes.

The presentation of the information model developed in this report does not follow the STEP guidelines for the formal presentation of information models such as application protocols (STEP, 1991a). The report is primarily an investigation into the information models needed for the integration of information used throughout a building's life-cycle, with light timber-framed houses as the worked example. The formal documentation and proper separation of diverse models is of little concern; rather a model is developed and explained, which combines diagrams and ideas from diverse models, with the appropriate references. Formal structure is only needed in the submissions to the standardisation process.

The status of the information modelled and structured in this report is only an initial attempt. The time available to analyse the information and the study of the STEP standard and existing building references places a limit on the coverage of such a huge subject area. The diversity of houses is not covered, but NZS 3604:1990 covers at least 80 % of houses constructed each year in New Zealand.

For a residential building, the data is archived and future reference to it is only made when any renovation work is proposed. However, with the new concept of automated homes, a large part of the information will be constantly in use, as part of a home control program. This includes the knowledge of distribution systems such as the power and communication and control systems. For very advanced "smart houses", volumetric information for people movement monitoring will be used. See Dechapunya (1991) for an overview of automated home systems.

Fundamentals

We start by referring to the general building systems model, which contains fundamental concepts. Each aspect of a general building system is an object: system, system component, system component port, system component port joint, system zone, system zone component. The structure of a general system is discussed later in this section (page 22), and in Figure 7.

A universe is composed of a collection of objects. An object may be decomposed into zero or more objects, as Figure 5 illustrates. Most objects go through three phases:

- **Generic:** An example is an aluminium 2400mm by 1000mm right hand sliding door. Attributes to do with colour, manufacturer, etc. are not specified.

- **Specific:** An object for which most product descriptive attributes are known. A particular product has been chosen for the job.
- **Occurrence:** When the location and orientation of a specific object has been determined. Each instance of a type of object has one and only one location and orientation. A location may be exact (x,y,z coordinates) or approximate (the second 2500mm by 1000mm aluminium door on the north wall).

A building project has a phase and a type (Figure 6).

A project's phase is the common set of time and order-dependent steps or events which make up the design, construction, use, and demolition of a building project. As a project advances the type and form of data generated and consumed increase dramatically. Ideas are refined and decisions made.

A more restricted term 'building project' is used here in place of the acronym AEC (architecture, engineering, and construction) which is not commonly used in New Zealand.

A building project has the building and the site (the environment in which it is placed). A building creates the internal environment that contains a building system. The site is the external environment. The environment contains all the information associated with the building in general and is more than just the climatic data.

There are a number of building systems that connect to site systems as shown in Table 2.

Table 2: The connection of building systems to site.

Building System	Site
Foundations	Cleared ground
Water	Water supply services
Waste water disposal	Drainage
Gas	Gas supply
Electricity	Electricity supply
Voice and data communications	Analog or digital telephone
TV	Frequency spectrum
Living spaces	Paths, patios, gardens, play areas, orientation

A building has one or more building properties including: number of floors, floor to ceiling height, area, cost per area, address, primary activity, secondary activity, structure type, enclosure type, building orientation, floor elevation, appearance, and location.

Similarly, the site has properties. Climatic data required for ALF, etc. will be added to the site property attributes.

General System Definitions and the General AEC Reference Model (GARM)

A general system definition is a framework for models such as our timber-framed house (Figure 7).

In the GARM definition (STEP, 1990b) a system is described as being designed to be able to generate a certain set of desired outputs for a particular range of system inputs, fulfilling natural and human needs. This area of abstraction is not attempted here.

What is used here is the concept of the general system hierarchy: a system, its components, and subsequently their component ports and component port joints. This system hierarchy facilitates the concepts behind the general AEC reference model. It deals with functional requirements, and alternative technical solutions to fit the requirements. Each technical solution produces subsequent functional requirements of its own. For example, the roof has systems that have requirements to resist vertical and horizontal loads. The objects that solve 'the requirement', are a bracing system or the rafter system. They connect (or port) to other systems such as a walls.

A system is conceived as having a component, simply to avoid unnecessary creation of systems to describe all objects. A system component may be defined as a system as well. This allows for a system to be modelled as a set of parts, assemblies, or sub-systems. A system or system component has its function statements, and a name and identity. It is noted that in engineering design, a functional unit is generally designed and specified rather than a single "atomic" part (e.g., a valve, or a load-bearing stud wall, rather than a list of parts). A wall is a component of the interior, acoustic, weather-proofing, and structural systems, and has different functions in each.

The port and port joints have to do with the interfaces between different systems (interconnection) or parts of the same system (intraconnection). The component port can be binary in that it connects with a port of another system component. A component port can be unary: a terminal that doesn't connect to anything else. A common example of a terminal is a meter, which provides an indication of the system's state.

The system port joint is the connector between two system component ports. It is realised as the fixings, connectors, etc., in buildings. The spatial system in a building could be viewed as having components, rooms and stairs, consisting of intraconnection ports (internal doors) and connected to the outside environment via interconnections (external doors). The components are interconnected by a circulation system.

A system is divided into system zones and system zone components (e.g., living areas or general floor areas, and eaves as a component of the roof).

Building System Classifications

Two alternative classifications of building systems are presented. The first is based upon distribution systems (right side of Figure 8). It is split into active, passive, and associative sub-systems. An active distributive system carries fluid, electricity, or air. A passive system carries less tangible throughput such as loads. The other system types are those associated with the building system (enclosure and interior).

The second way of classifying building systems is to look at space, fabric and services (left side of Figure 8). This classification scheme, focusing on the fabric, is developed in this report. The information processes and topics reviewed (guides to building via NZS 3604:1990, ALF manual (Bassett, 1990) have to do with the fabric of a house.

Structural Systems

Going now to the structural systems model (Figure 9) a structural system is defined as having associated with each structural system component, a grid group and a structural assembly (with structural elements). Each structural element can be free-form, linear, planar, or a fastener or connector. Linear and planar elements are further defined (Figure 10). An element is an object that cannot be further sub-divided into other objects. This may be a matter of perspective, for example a rafter can be just a specified rafter, or the individual parts of an "I" beam assembly of plywood and timber members can be listed.

The spatial system model (Figure 11) has system components for the building's enclosure and interior space. Interior space can be occupied, or form part of the building's distribution systems (ducting, etc.). Occupied space can be circulation, service, or assigned to a specific task. Examples are: a hallway, a hot-water cylinder, and, as a specific task, the living room. Each space has assigned properties for geometry, environment (acoustic, lighting) and other associated attributes such as room type, activity, etc.

3.5 The Data Model

The data model presented in this section is based upon the systems hierarchy developed in Section 3.4. This is a brief summary of the data model, representing common knowledge about light timber-framed construction. The data model still requires further development and refinement. The information presented here will next be specified in the EXPRESS information language.

The Overall House

The house structural model has four systems: foundations, floor, walls, and roof.

Figure 12 (Rush, 1986) is a basic model of all 'system connections' of a typical building, using four basic building systems. Rush (1986) organises buildings using the concepts of: structure (S), enclosure (E), mechanical (M), and interior (I). The type of connectivity (remote, touching, connected, meshed, or unified) is denoted by the size and links of each circle in the diagram.

Figure 12 combines these two different systems schemes together. A scheme based upon major building parts (foundations, floor, walls, and roof) is followed here.

Foundation Systems

NZS 3604:1990 describes 13 foundation systems as possible combinations of components for single- and two-storey buildings.

Figure 13 is a preliminary NIAM (Turner, 1991) diagram for a foundation system. There are two sets of system categories: systems to resist vertical and horizontal forces, and their location: internal (inside the foundation wall perimeter) and external (on the foundation wall perimeter).

Foundation System Components

Components consist of assemblies of foundation elements (see below). In Table 3, each component is marked for its membership of the four systems categories described above. A particular element can appear in more than one component. Some of the groupings may be unusual to the reader, but they are grouped together where they contribute to a particular system and are a component in one of the layouts presented in NZS 3604:1990.

Foundation System Elements

Elements identified are: piles (braced, ordinary, anchored, deep or shallow), foundation walls (corner, perimeter, pier), jack studs, bearers, diagonal braces, and sub-floor (walls which can be split into wall elements).

Foundation System Component Ports (objects that interface between systems)

These include:

- Connections to the sub-floor framing, ground;
- Connections to the house, i.e., the floor, via the bearers and floor joists;

- Connections between foundation elements.

Table 3: Foundation system components

	Systems to Resist Forces		Location	
	Vertical	Horizontal	Internal	External
Braced + ordinary piles	x		x	
Short driven shallow cantilevered piles	x		x	x
Short driven deep cantilevered piles	x		x	x
Ordinary + anchored + piles	x		x	x
Ordinary + braced + anchor piles	x		x	x
Corner foundation wall	x	x	x	x
Perimeter foundation wall	x	x	x	x
Single skin brick and pier foundation wall	x	x	x	x
Jack studs on anchor piles	x		x	x
Masonry infill wall between piles	x	x	x	
Structural floor diaphragm (located remotely from rest of foundation components)		x	x	x
Rows of diagonal braces		x	x	x
Individually placed diagonal braces		x		x
Diagonal braces fixed to anchor piles		x	x	x
Anchor piles fixed to bearers or joists		x	x	x
Subfloor wall	x	x		x

Grid Groups for the Foundation System Components

Each system component is an assembly of foundation elements that form a line or are placed on a line. There are three types of foundation lines: the internal lines that run in the two orthogonal directions of the house, and the perimeter outline. Associated with these grid lines are the bracing schedule (required and as-designed). These are either a total bracing value of the whole line or for pieces of wall on that line.

An Overall Grid Group for Load Distribution to the Ground

The main function of roof, wall, floor, and foundation systems in our model is the distribution of vertical and horizontal loads to the ground. Earthquake horizontal loads are distributed through the structure and foundation to the ground. Rigidity of the structure

is important. In NZS 3604:1990 there are many instances of vertical alignments of elements (an element close enough to a element below it, to transfer vertical loads). There are also load distribution paths for horizontal forces. Two grid groups are required for horizontal and vertical load distribution. These two load distribution grid groups are building-wide.

Floor Systems

There are two types of floor systems for timber houses: suspended and concrete slab-on-ground. The choice is quite simple as compared to commercial construction which is quite varied in form.

Floor System Components

For suspended floors, two system components arise:

- a run of floor joists and their lateral bearer support components,
- the flooring.

Floor System Ports

System ports are the respective connections to the foundation and the connections to load-bearing and non-loadbearing walls. The foundation port can be realised by bearers supporting the joists, or the external foundation wall.

Grid Groups for Floor Systems

Grid groups associated with floors are the structural spacing associated with rows of joists, and the vertical and horizontal load distribution grids introduced with the foundation system.

Wall Systems

In NZS 3604:1990, the function of the wall framing is to:

- provide resistance to the vertical and horizontal loads acting on the building;
- provide support for the external cladding of the building;
- provide support for the internal linings and fittings of the building;
- transfer loads acting on the roof and walls to the foundations.

Figure 14 is a NIAM diagram of the wall system model.

The walls of a timber framed house consist of the structural framing system (with a series of sub-systems to resist vertical and horizontal loads, and transmit them to the foundation), and the external wall cladding that provides protection to the interior from the external environment.

The general framing of a two- or more storey building is classified by the framing layout of the walls and intermediate floors: commonly referred to as either balloon (not common) and platform.

Other classifications of walls are by location (internal or external), by loadbearing capacity (loadbearing, and non-loadbearing), and construction material (timber stud with cladding, brick veneer, and masonry or concrete walls). With reference to internal space separation requirements there are partition and party walls (only in semi-detached buildings).

Wall System Components

Wall system components are the timber framing, the bracing, and the cladding. Each of these components comprises assemblies or groupings of common wall elements.

Wall System Elements

They are: studs, plates, lintel beams, linings, wall bracing, etc.

Wall System Component Ports

Wall system component ports include connections between the wall and:

- cladding;
- window and door frames;
- floor, foundation wall (ribbon boards, bottom plates);
- other walls at corners (corner posts) or other wall junctions;
- roof and ceiling;
- wall bracing elements.

The Window System Component Port

A subset of wall system ports is the connection to windows. Ways of classifying them are:

- by extension, location, or connection (Rich, 1982): for example, hole-in-wall, gap-filling, and window-walls. The last two are mainly seen in commercial multi-storey buildings, so are not considered further.
- by material (NBA, 1975): for example, timber, steel, aluminium, and plastic.

The window frame is connected to the wall. In terms of our general system hierarchy the window frame is a system component port. It is an assembly of top and bottom horizontal members (the head and sill) and vertical sides (the jambs). The system component port joints are the various objects that connect the frame to the vertical and horizontal wall members (studs, trimmers, jack studs, lintels).

The composition of the wall-window junction is determined by the wall type: whether it is brick, timber frame, concrete, etc. For timber-framed houses, the cladding system (timber, brick, etc.) is considered too.

Additional items to be accommodated at the wall-window interface are; building paper, interior wall lining, dwangs, brick cladding and cavity, cavity closer strips, special sill bricks, brick lintel support, flashings, interior trims, and a wide range of claddings.

Considered separate from the structural wall-window junction is the weather penetration resisting system. Bassett et al. (1991a) outlines common seal systems. They describe six mechanisms for water penetration. A common drained joint for windows consists of an assembly of components: a rainscreen, a drained cavity with drip edges, and an airseal.

Roof Systems

From an analysis of NZS 3604:1990 and some roofing system reference books, the following system, component, and assembly schemes arise.

Roof framing:

- supports the roofing material;
- resists loads on the roof (wind, earthquake, roofing weight, snow);
- transfers wind and earthquake loads acting on the roof to the wall structures;
- supports the internal ceiling linings.

Roof System Components

A roof's vertical support system has rafter or truss alternatives; close-coupled, collar tie, flat roofs. Roofs are also classified by their outward shape. Specific roof classifications are the hip or gable alternatives, and light or heavy ($> 20\text{kg/sq m}$) weight.

The truss is a common vertical support system. Truss dimensioning is usually set out by the truss manufacturer, or specific design is required. Trusses or rafters support purlins, which support the roof covering.

For rafter-type roofs where no trusses are used, the horizontal member at the apex of the roof is termed a ridge board, which the rafters are leaned against (nailed, but which carries no vertical loads), or a ridge beam that provides vertical support to the rafters. The ridge beam requires stronger connectors to the rafters than the ridge board, and will have a load-bearing post or wall to transfer the load to the foundations.

Roof System Component Ports

There are a number of roof-system interfaces to other building systems: roof to roof covering support system (purlins, sarking), roof to eaves-soffit lining and guttering, roof/ceiling (ceiling hangers, runners, battens). The ceiling lining can be directly connected to the rafters (skillion roof) or to ceiling framing (couple-close, etc.).

In-roof penetrations are dormer windows, chimneys, skylights, vents, and overflow pipes. Their surrounds require trimming timbers.

Roof System Zones

There are a number of planar intersections between roof planes (roof-roof connection) and walls (roof-wall connection). The framing at these junctions are hip and valley rafters, verges, etc. Rafters are called common or jack, depending whether they go the full rafter length.

The Eave is the generic term for the area where the roof rafters connect to the wall framing. The soffit is the underside of overhanging eaves, and there are a number of ways to line the soffit.

Verges are another zone where the wall joins to a gable roof, where the roof slopes in line with the wall line. Verges can be flush with the walls or overhang (in which case cantilevered purlins or outriggers are used).

There is a horizontal support system (along the roof ridge direction) consisting of long-length timber bracing in the roof plane (diagonal bracing) or in the roof space. The support must connect to a wall element that has sufficient bracing. Hipped roofs require less bracing due to the inherent bracing in their triangulated shape.

Grid Groups for Roof Systems

Roof dimensions include the rise and run of a rafter. The span of a roof is the unsupported horizontal dimension over the space covered. Rafter maximum span is defined as the dimension between supports on a rafter. In NZS 3604:1990, a roof dimension 'S' is used

to size the load-bearing wall's framing members.

Figure 15 is the NIAM diagram for roof systems. Figure 16 lists the typical roofing structural members.

3.6 Views on the Building Data Model

All applications such as drawings (2-dimensional, 3-dimensional, etc.), specifications, and reports for schedule of quantities, and costing work, will be a view on the central database (see Figure 1).

For each of these applications a 'mapping' is required from the basic building objects to representation objects such as lines and curves on a drawing. These mappings are themselves whole new areas requiring information modelling. Much of this work has been standardised in some of the STEP application protocols (Warthen, 1990). This work does not include any such modelling. At this stage in the data model development, only the basic statements of what each view is are noted.

Drawings and Details

These include the plan, elevation, with the dimensioning of the building and the site layout, and the detailing of any system requiring further explanation. Details include the following basic structural exterior, and interior systems. Typically junctions between systems are detailed as follows (Trada, 1970):

- The corner of two external walls showing typical connections of framing and alternative claddings.
- The external wall and ground floor showing typical wall cladding and methods of framing with suspended or slab-on-ground construction.
- The external wall and first floor showing typical wall cladding and methods of framing.
- The external wall with pitched or flat roof showing typical wall cladding, methods of framing at verge, eaves and gable end.
- The party walls and partitions with ground floor, and first floor.
- The party wall and partition junctions with pitched roofs.

Construction consent applications require plans and details of the house systems to show compliance with the New Zealand Building Code.

Specifications

A specification consists of text statements that describe system and product requirements to fit the design solution. The specification should state what the materials are, their physical properties, their performance characteristics, and all other pertinent information regarding the elements of the work. The clauses within a specification are a mixture of design choices and standard working practices that remain constant between different designs. Specification writing implies detailed knowledge of resources (materials and skills). Often the specification describes information that could be illustrated on detailed drawings, but is not. On the other hand, the specification often duplicates information in the drawings so as to ensure the understanding of the design.

4 Discussion

General

The work initiated with this project is the modelling of information, and the development of conceptual models of light timber-framed houses. The work here, at this stage, is quite separate from implementation of the models on a computer. The modelling work was confined to structural objects in light timber-framed houses. To define the boundary of the model the text references on house structure were collected, with specific reference to NZS 3604:1990. Past work with code of practice computerisation provided another source of ideas.

The need for the proper discussion of data structure has been recognised by researchers (Bjork, 1990) who have embarked upon building modelling work aimed at, eventually, computer-integrated construction.

The communication of ideas is important for the developers and users of computer-integrated applications. The time will come soon when current technologies such as graphics engines, database servers, and object-oriented programming languages will be well-established and standardised, very affordable, and easily applied. The major effort involved in program development on a large design project will be the development of the data models. If the 'product data' movement is successful, computer-integrated construction will be utilising specifications for their program's data structures, rather than relying upon some hidden proprietary structure provided by the computer program's vendor.

The NIAM (Turner, 1991) diagrammatic notation has been used to communicate some of the ideas on building systems structure. NIAM has been criticised for not including rules or formulae. For example, Amor (1991) dismissed the NIAM notation for its lack of support for rules, and is seeking a higher-level representation. A building is a complex collection of objects, with many inherent rules for their composition. The EXPRESS information modelling language can be used to extend the model with rules.

Extending the Data Model and the STEP Protocols

We have so far started to model the building objects. The integration of graphical presentations such as drawing views of a building, requires models on top of the basic building system hierarchy. It is here that some of the STEP standard application protocols should be used to extend the data model, from the basic objects, to include views of the objects (see Figure 1).

An application protocol is an information model that tells how to use a certain pool of standard objects for a particular subject area. The two parts of STEP of interest here are the application protocols for drawings: explicit draughting (the drawing generation and maintenance) and associative draughting (the drawing and detailed design). Current

development within STEP is the building of a framework for classifying and integrating the many application protocols developed so far.

The current state of the proposed data model is far from implementation on a computer. The data model comprises a 'high-level' systems/objects hierarchy. What remains to be done is the assignment of attributes to the basic objects within the hierarchy. The developed data model will eventually be specified in the information modelling language 'EXPRESS' (STEP, 1991b). An EXPRESS specification will then be implemented in a computer in C++, along with the development of a prototype interface to the database.

Conclusions

The work reported here involved the study of a well defined subject area (information on New Zealand light timber-framed houses, mainly in a code of practice) building upon existing general building system models.

The work of information modelling was difficult at times, but with careful study, the relationships between objects were represented in a systems structure. The resulting structure of the data model is not complex.

The development of models requires a lot of effort. The expense incurred will be justified for those who require computer-integrated construction. The major part of the communications problem will be solved: where an information model doesn't exist, re-input and interpretation of complex databases of objects has to occur.

Use of existing models (such as the general building systems model (STEP, 1990a) and standard methodologies (STEP, 1991a) is needed for the development of common data models.

The current model does not encode all the information within the code of practice (see Hamer (1990) for code of practice knowledge representation) but is the start of a general building data model that will be the basis for computer-integrated construction.

An important question was whether the emphasis on reference text study is sufficient to develop a computerised data model. Development of the model will require co-development with some computer implementation. Modelling physical and abstract objects from text books must be in conjunction with realising them with the data models inherent in current information technologies. Such technologies are databases, programming languages, and the geometries of CADD systems.

For research purposes, the data model developed here was developed through study of a chosen subset of house information (NZS 3604:1990). For use in an industry, any information/data model must also be in conjunction with pragmatic hands-on knowledge, built by some representative working group of experts in the particular industry.

Will the information modelling be useful? Time spent on summarising concepts must be realised in demonstration applications. A comprehensive model that can cover a number of views of a house, combined with standard models from STEP, should be pursued as the means to form an information architecture as a basis to build computer integrated tasks for a house. A central data model that can represent the semantics of a building to a computer is a long-term, complex research challenge.

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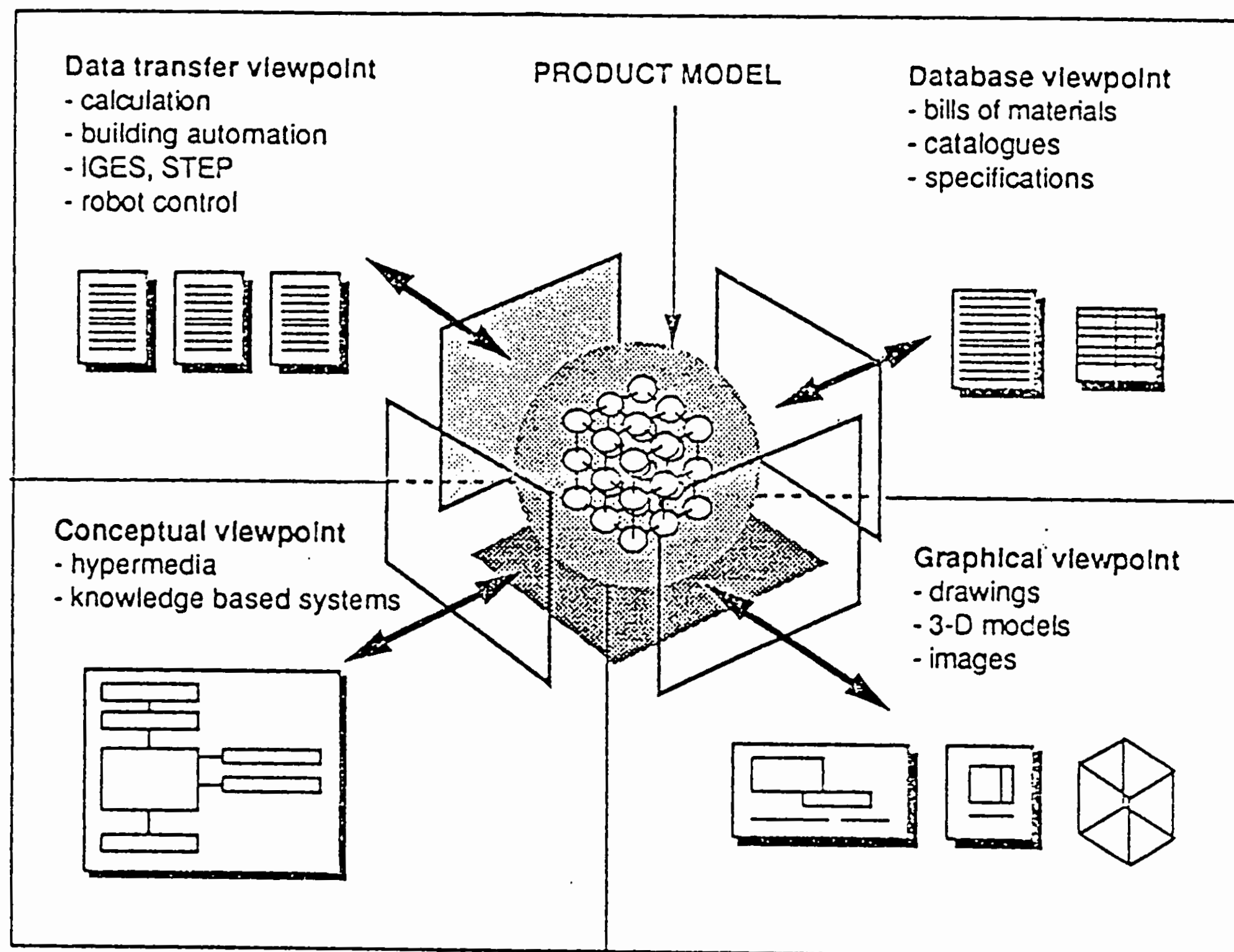
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Product modelling is a very complicated subject. Different viewpoints point out different aspects of the model, but none of them completely describes the whole model.

Figure 1: Conceptual views of BDM information and a common database (Bjork, 1989).

	<i>Modelling Activity</i>	<i>Scope</i>	<i>Size</i>	<i>Status</i>
<i>Standards</i>	STEP	Most AEC areas-general and specific applications	A series of standards each specified by the EXPRESS information language. Parts still to be developed.	First draft Major concensus activity within IPO.
<i>Major Research Groups</i>	VTT's RATAS	As-built commercial offices	50 object classes 500 inter-object relation no geometry	Mature, industry collaboration, four prototypes.
	STEP Research Projects	Concerned with general data model integration issues.		Submission to IPO for STEP management
	Esprit Projects	General AEC. Contributes to STEP	Mainly AEC. geometry.	
	CALS Initiative	Aerospace makes use of STEP		
	COMBINE	Energy Performance Early Design	Developed a set of prototype performance tools	15 partners from 8 countries. Initial pilot study finished.
	CIMSTEEL	Structural Steel	A pan-european project	
<i>Local Activities</i>	University of Auckland's ThermalDesign+ WallBrace	Thermal analysis and code of practice representation	Hundreds of derived objects. A building abstract representation and code rules	Model will be developed as an integrated application is developed.
	Amor's Common Building Model	Thermal analysis, Early architectural design	looked at 26 thermal analysis packages 36 classes, 80 attributes integrating 3 packages	data model established, with mappings, prototypes under development
	Branz's Residential House	As-built, structural and operation	< 100 objects still under development	Just basic data structure, requires refinement
	CSIRO NBTC	Project Decision Database	Chooosen a few building objects as examples.	Early stages, specifying requirements.

Figure 3: Existing data models world-wide, noted in this study

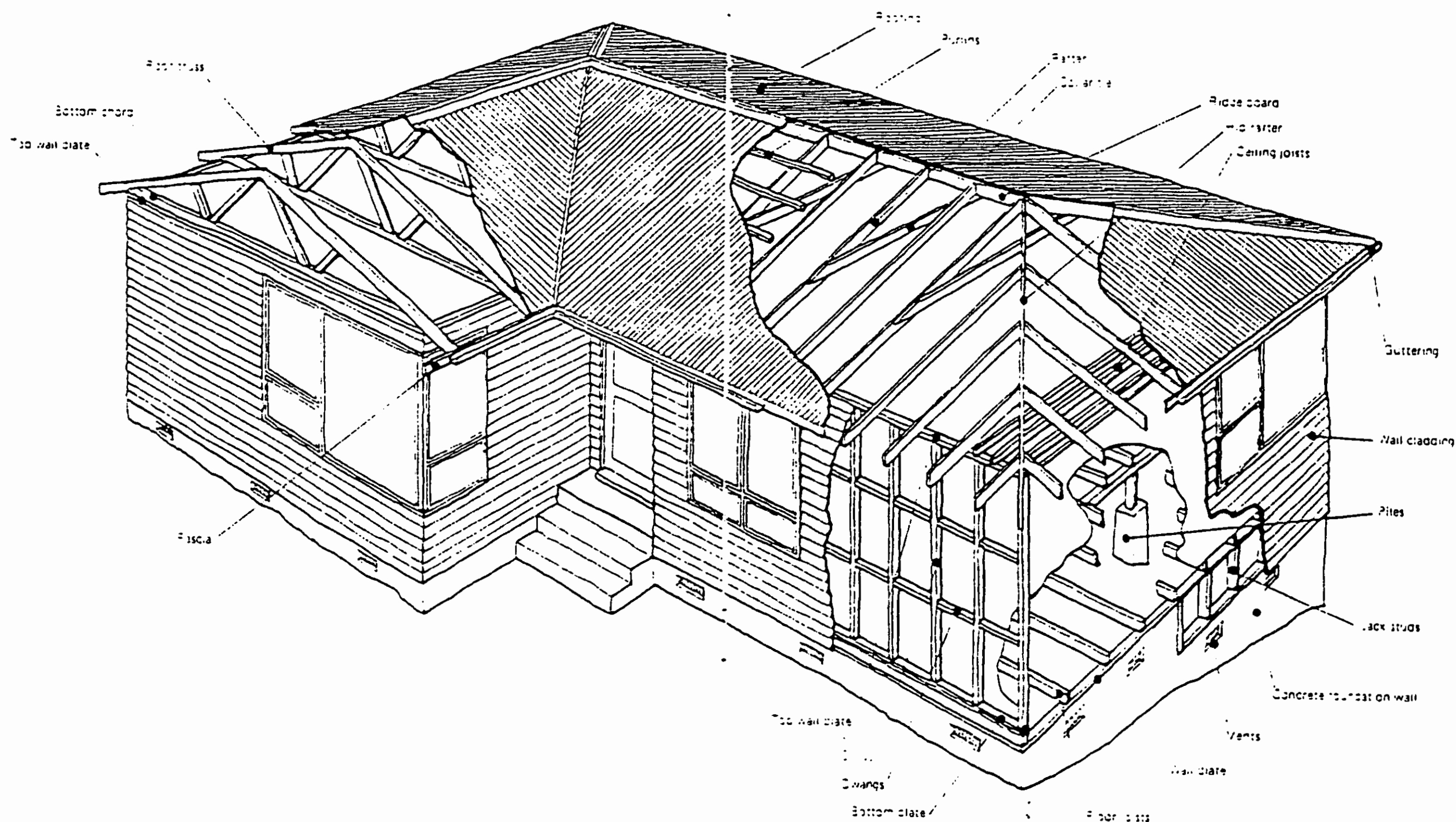


Figure 4: The model's scope: the structure of a light timber-framed house

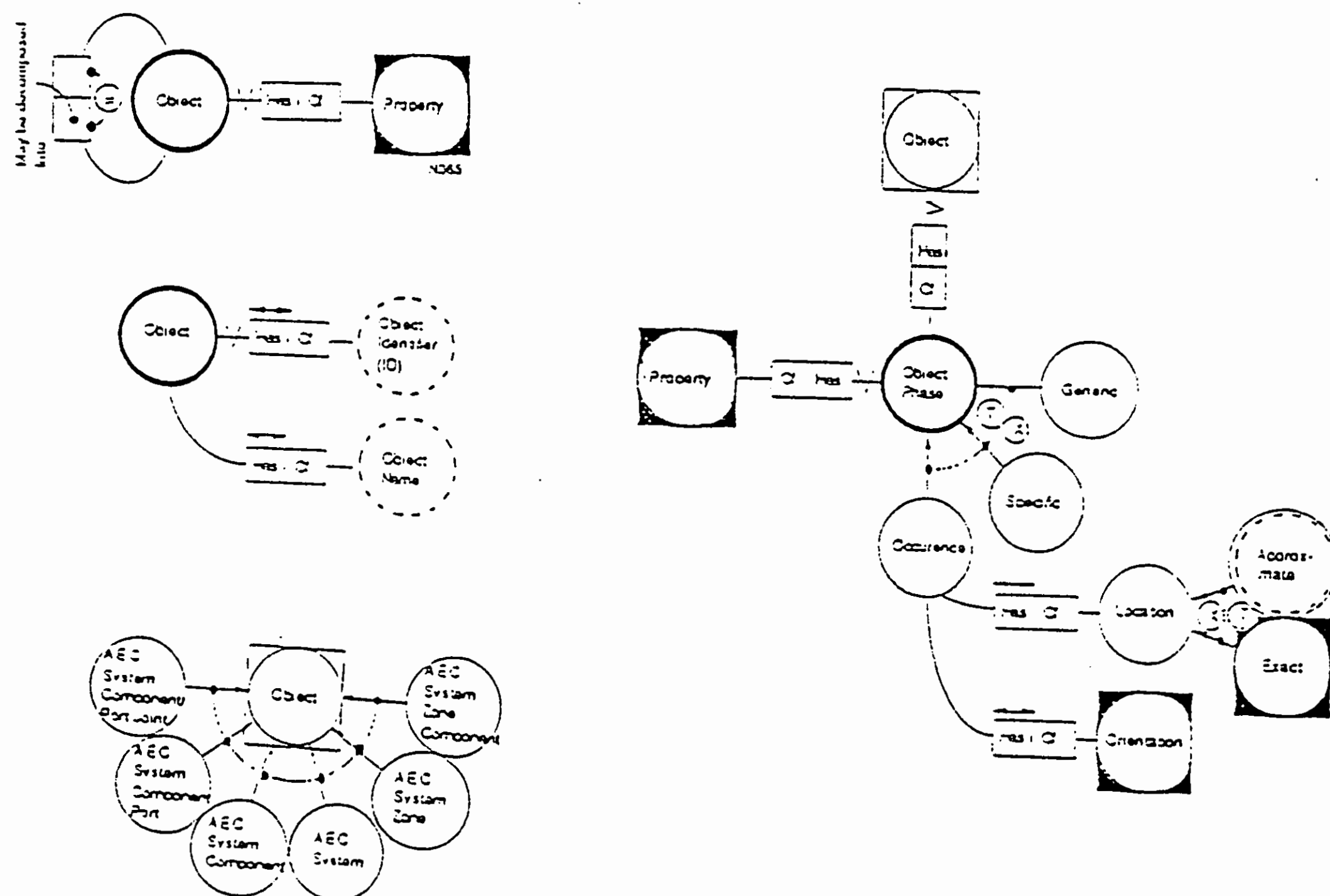


Figure 5: Objects (STEP, 1990a)

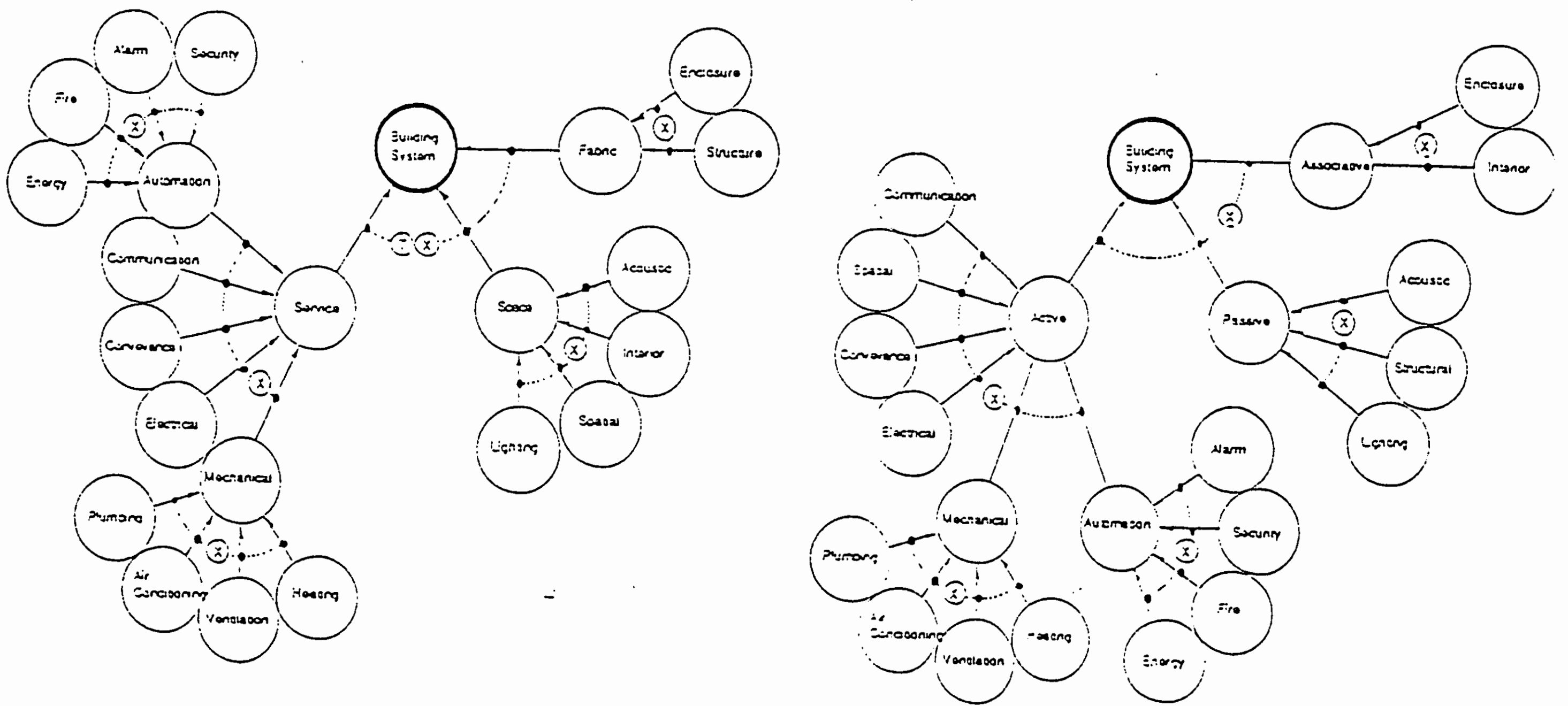


Figure 8: Alternative building system classifications (STEP, 1990a)

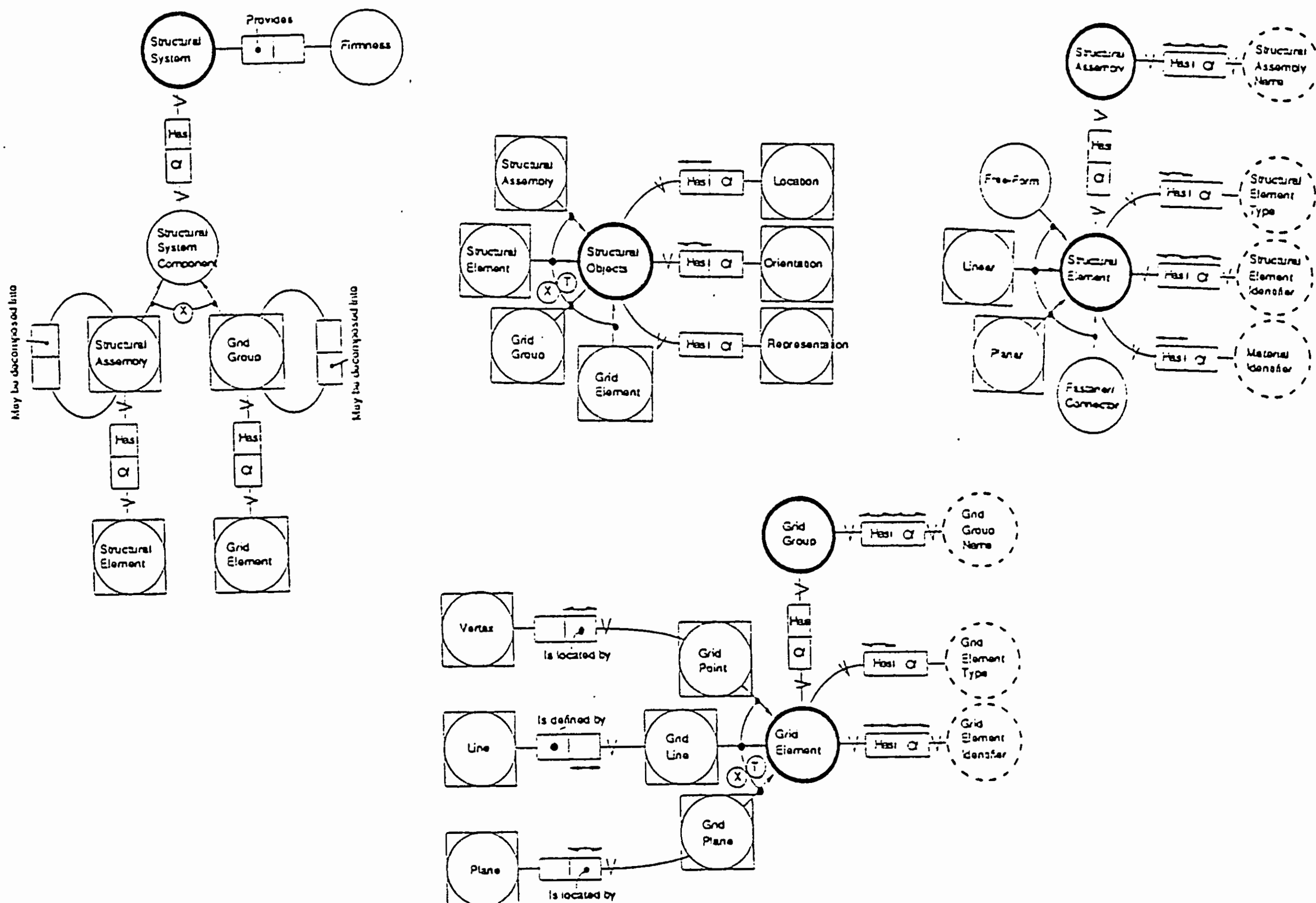


Figure 9: Structural systems (STEP, 1990b)

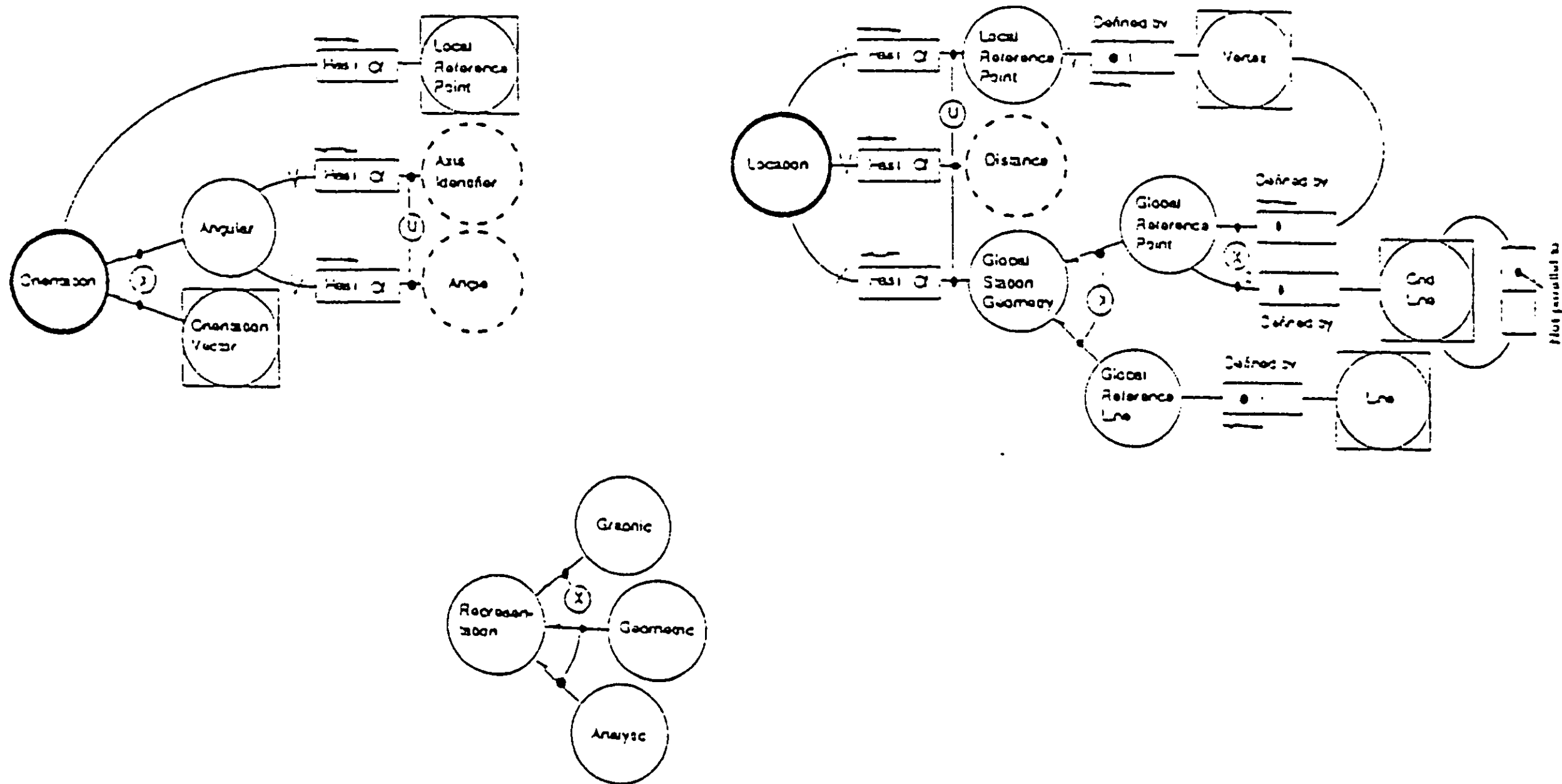


Figure 10: Basic geometry (STEP, 1990b)

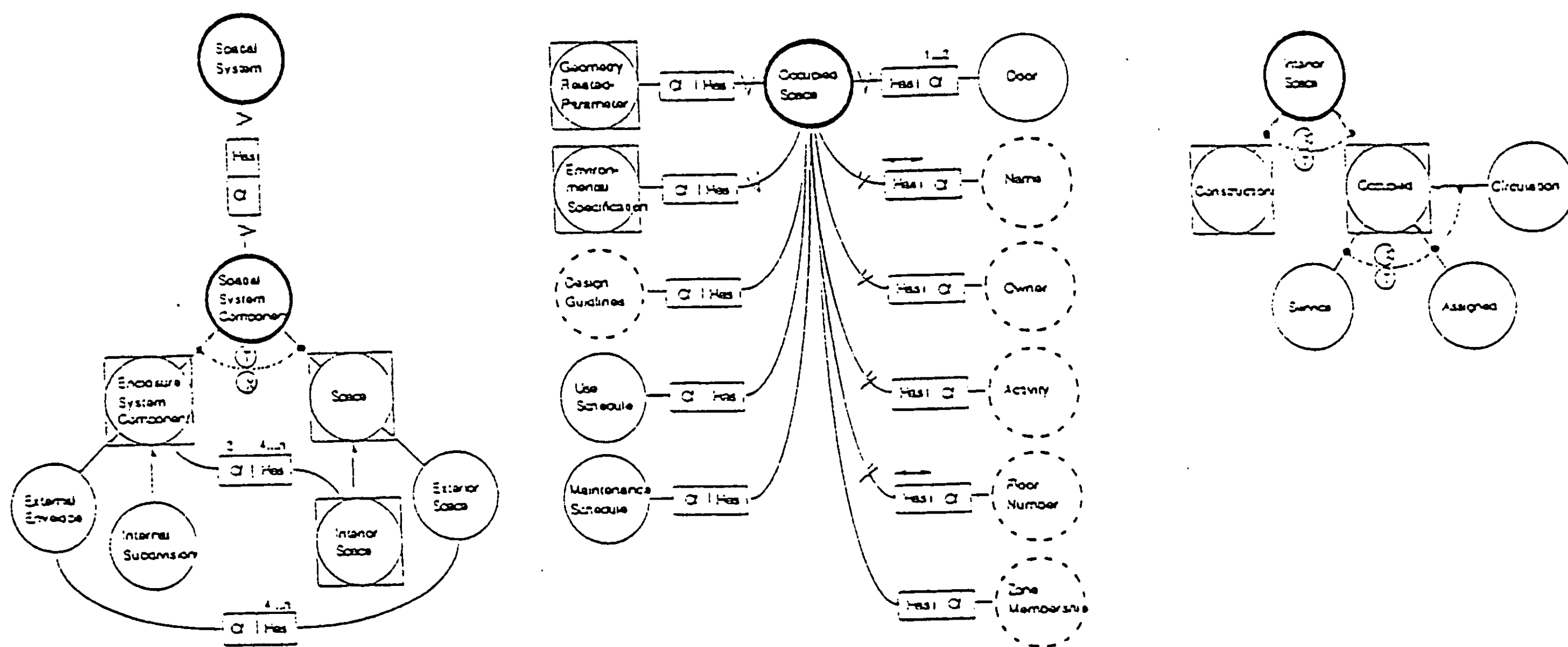


Figure 11: Spatial systems (STEP, 1990c)

Roof assembly

roof structure (S),
roofing (E), ceiling (I),
lighting (MI)

Wall assembly

wall structure (S),
exterior wall covering (E),
windows and doors (EI),
interior lining (I)

Interior floor assembly

floor framing (S),
flooring (I), furniture (I),
ceiling and lighting below (MI)

Floor/foundation

floor framing structure (S),
flooring (I),
plumbing, water, etc (E)

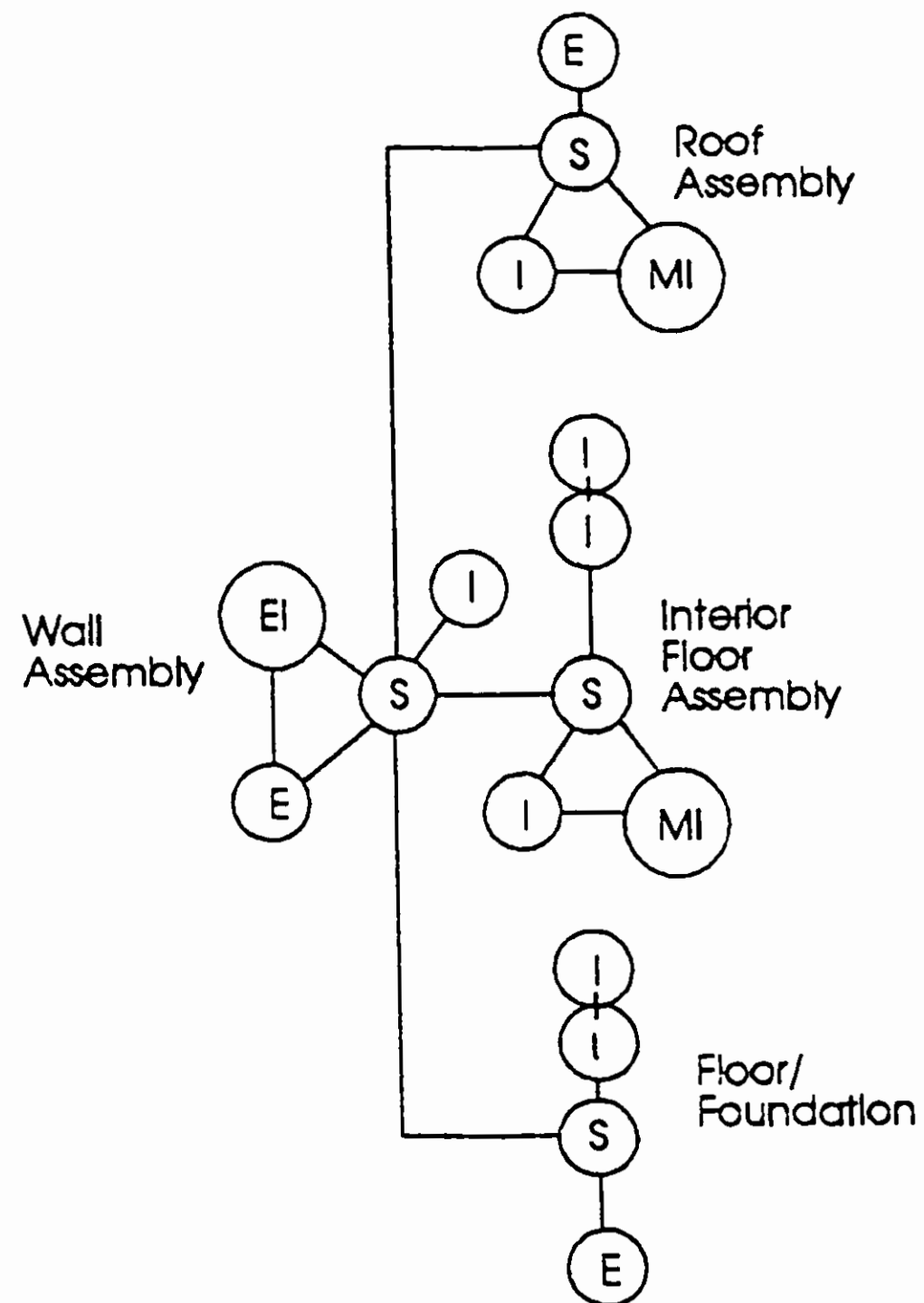
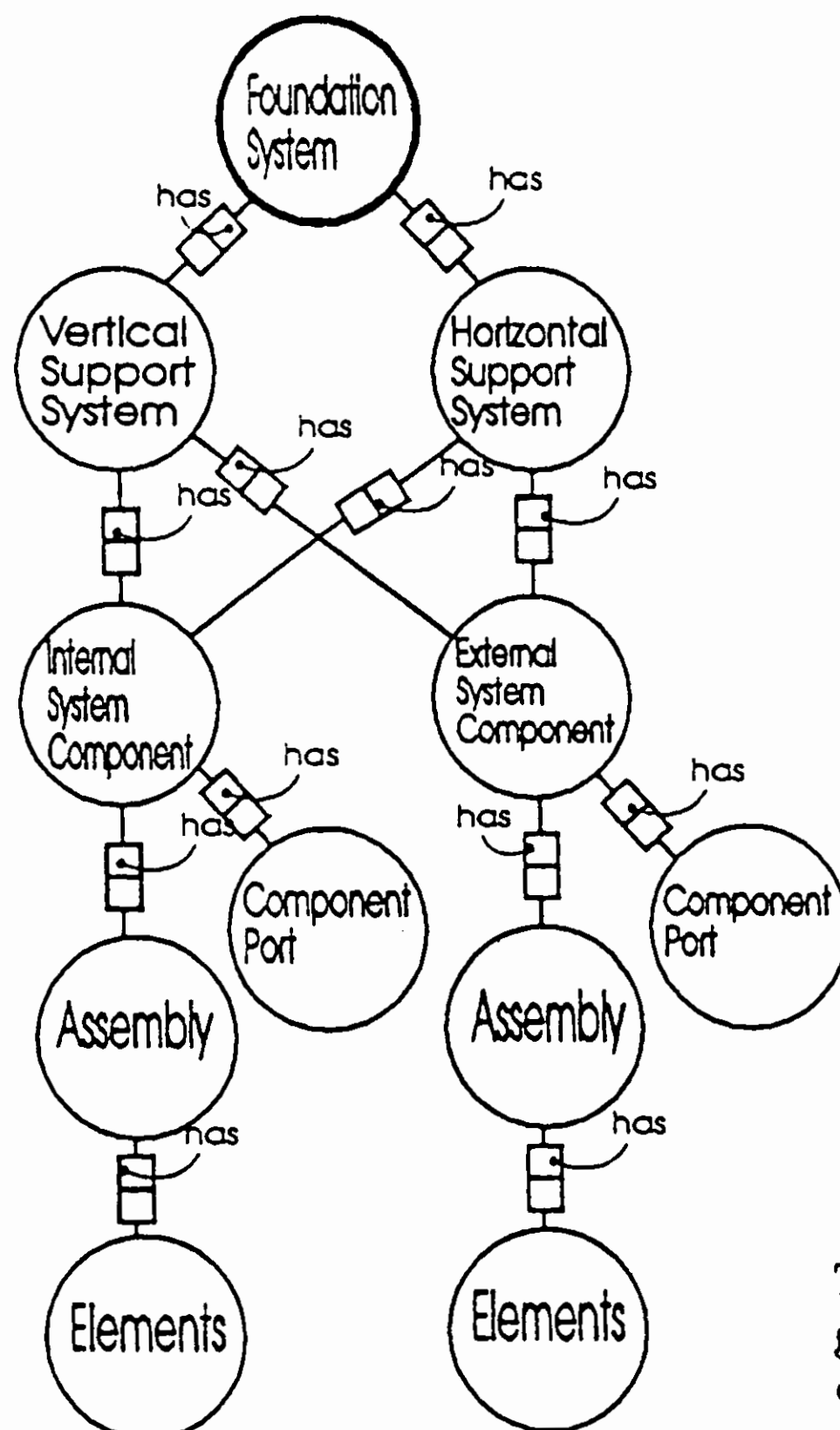
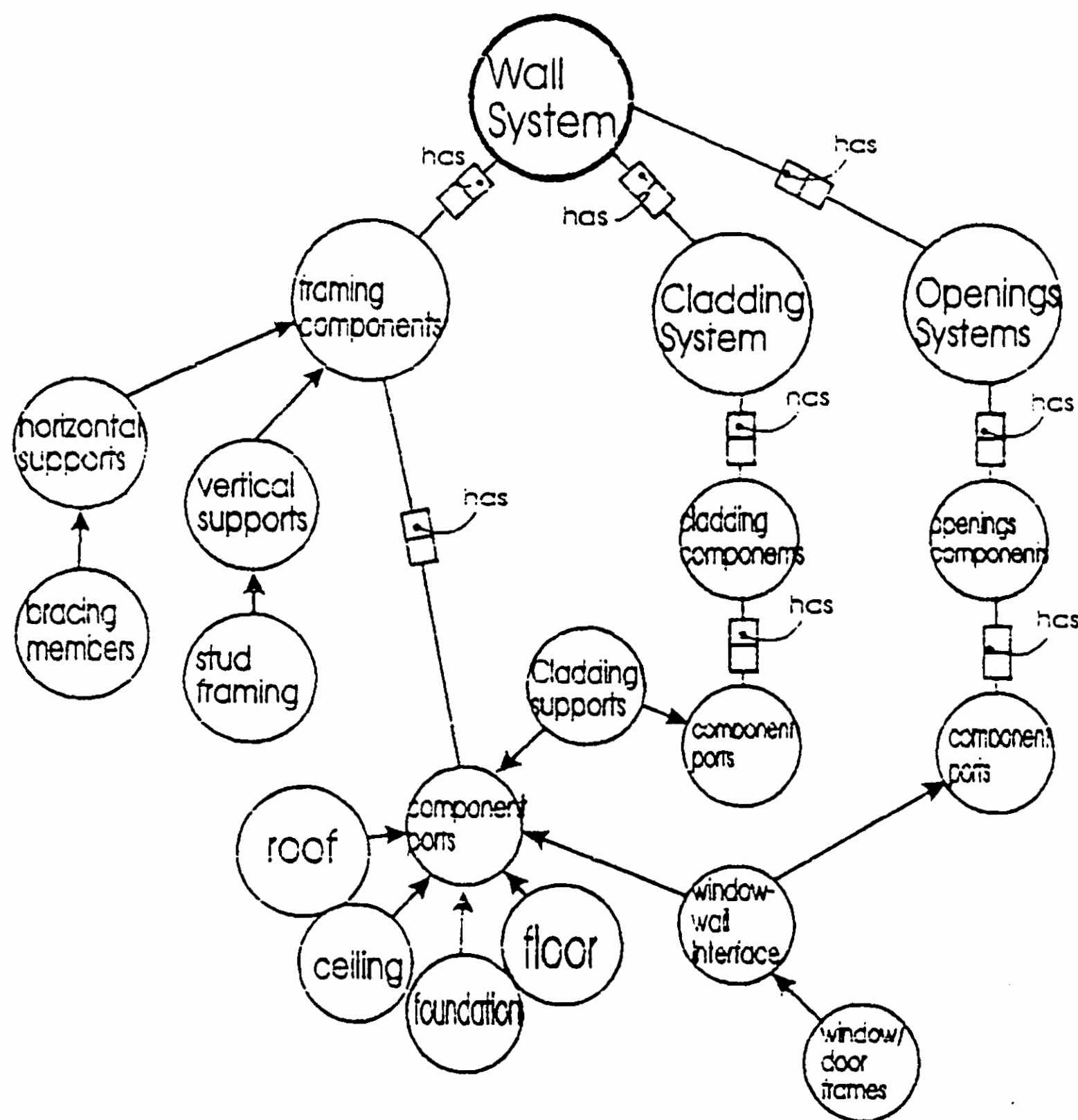


Figure 12: Typical building connectivity (Rush, 1986)



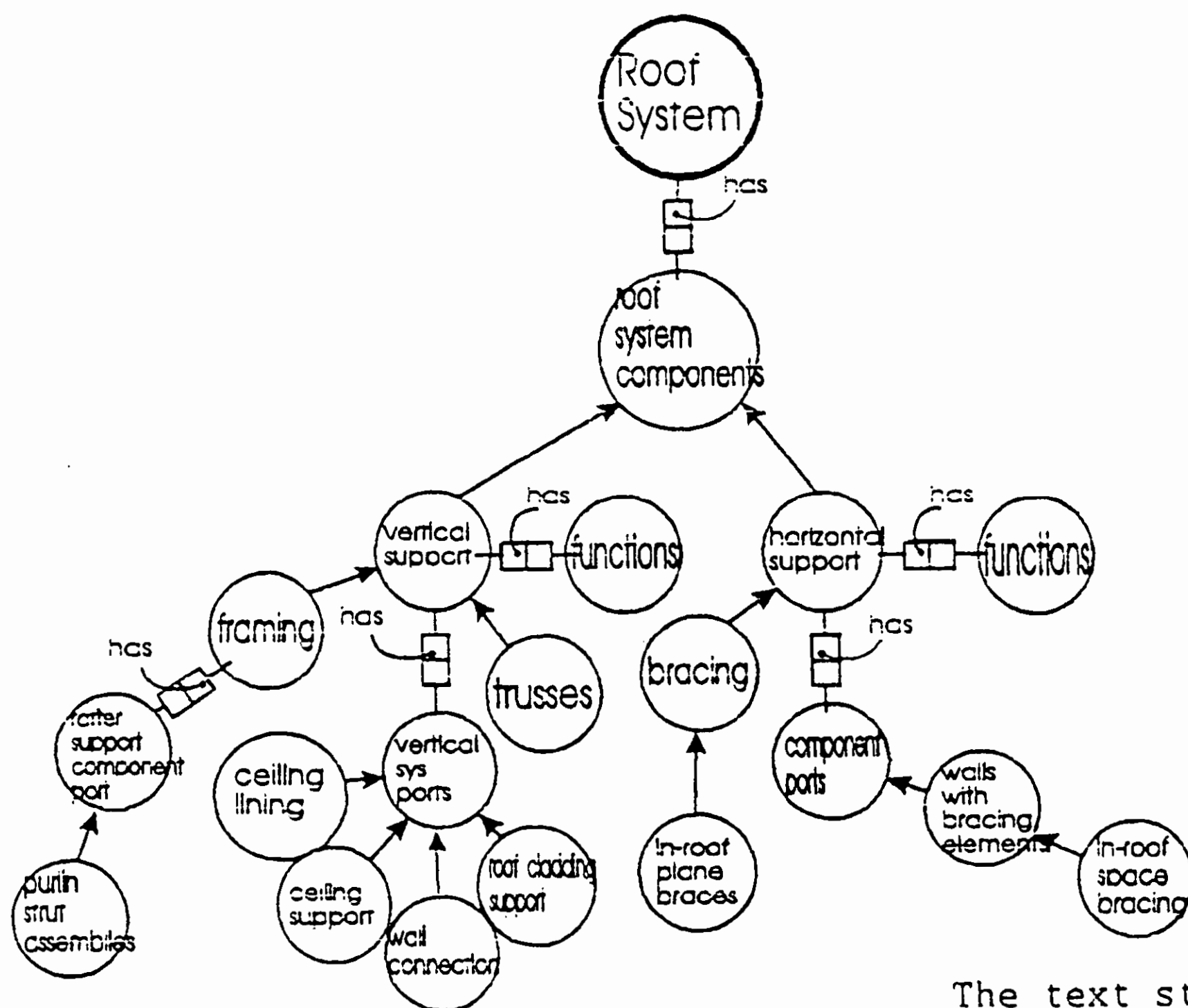
The text starting on page 24
gives instances of foundation
components and elements.

Figure 13: Foundation systems



The text starting on page 26 gives instances of wall system objects.

Figure 14: Wall systems



The text starting on page 28 gives instances of roof system objects.

Figure 15: Roof systems

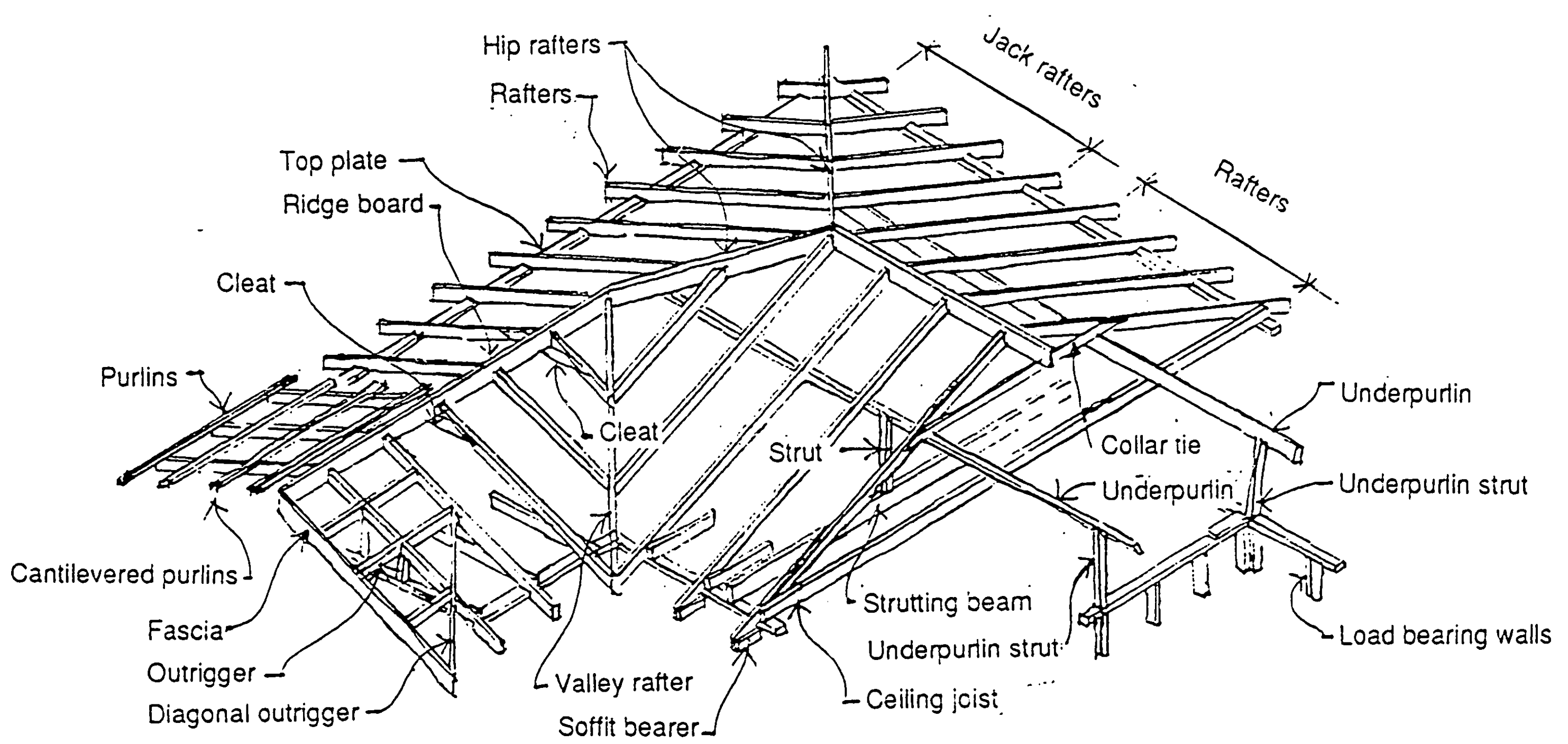


Figure 16: Roof framing members

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