A MODULARISED INTEGRATED COMPUTER ENVIRONMENT FOR THE CONSTRUCTION INDUSTRY: SPACE

SUBMITTED: July 1999
REVISED: November 1999
PUBLISHED: November 1999 at http://itcon.org/1999/3/
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SUMMARY: *This paper outlines an overview of the SPACE project. SPACE (Simultaneous Prototyping for an Integrated Construction Environment) is a rapid prototyping environment which supports a subset of a construction project life cycle. Its main objective is to develop a future intelligent integrated design and construction system for the civil and building domain through which a number of solutions can be generated and analyzed. This is accomplished through the use of a comprehensive project data model capable of supporting a range of applications. The data model consists of an independent data model and application specific data models. The research concentrates on establishing a project data infrastructure and tools for managing the information exchange that occurs during a project life cycle, with emphasis on the design, site layout and construction planning, cost estimating and maintenance applications. This will enable better, more efficient and more cost effective buildings to be designed. The output generated by the prototype are very detailed which can improve the decision making process, different constraints can be applied and their consequences can be simulated. The prototype was tested with a number of case studies, some of which can be viewed by downloading the demo file attached with this paper.*

KEYWORDS*: Computer Integrated Construction, Project Model, Integration.*

1. INTRODUCTION

The construction industry is fragmented by nature. The design process is separated from the construction process and the essential involvement of designers, estimators and other construction professionals exacerbates fragmentation. In the past, researchers have used IT for providing numerous decision support systems for the professionals involved in the industry. These systems have created “islands of automation” and are far from achieving an acceptable level of integration across disciplines and across the design and construction processes (Kartam, 1994).

It is recognised that greater benefits can be achieved if these systems are integrated. Thus, numerous studies have been carried out with the aim of integrating the various project life-cycle phases through IT solutions (Underwood and Alshawi, 1996, Ammermann et al, 1994, Amor et al, 1997, Aouad, 1997, Aouad et al, 1994, ATLAS, 1992, Augenbroe, 1993; Bjork, 1989; Dubois, 1995, Faraj and Alshawi, 1996a, Froese and Paulson, 1994, Tracey et al, 1996, Wix, 1997, Yau et al, 1991). A good review of some of these projects is in Brandon and Betts (1995). Due to the wide range of activities and professional views in the construction industry, many of the developed data and process models have either been developed for a specific stage or a few stages of the project life cycle. Consequently, many “isolated” models have been produced to tackle different aspects of the project life cycle. This isolation has reinforced current practices, failing to address fully the question of integration and related issues such as shared information, common processes, etc. (Yamazaki, 1995, Shaked and Warszawski, 1995).

Recently, there have been two major efforts in the development of standard data models, STEP and IAI. The latter is aiming mainly to produce standard data models; namely the Industry Foundation Classes (IFCs).

Evidence indicates that IAI has managed to gain the support of the industry. A number of IFCs data models have been released, the most recent is the IFC data model version 2.0 (IAI, 1999).

There is also a dichotomy between the processes of CAD and other Computer Integrated Construction (CIC) that inhibits the implementation of a fully integrated model of a project life cycle. Approaches that have considered the integration of CAD and CIC tend to concentrate on particular aspects of the construction information with little emphasis being given to the iterative nature of these processes and the need to feed back information between the various stages of the life-cycle.

This paper presents an overall view of the implementation of the SPACE integrated prototype and shows "live" demonstrations of the environment through the Web. It is an umbrella which empresses a large number of complex issues that have been developed for or considered by SPACE. References are given, where appropriate, in the text in order to give readers the opportunity to obtain detailed information about the environment.

SPACE uses a project model and application specific models which permit all geometrical and non-geometrical information required to design and construct a project to be represented. The paper outlines the structure of SPACE, its working mechanism, an implementation overview, and a discussion of its constituting applications.

2. WHY PROJECT MODEL?

Since the early 60s, computers have been used to aid design and other engineering applications. One of the earliest systems was Sutherland's "Sketchpad" (Sutherland, 1963) which was the first computer based graphic package. Today, powerful geometric modellers exist which are capable of presenting 3D models. However, their support to down stream construction applications is very limited. For example, it is not a straightforward task to transfer design information from a 3D modeller into an estimating or planning software application. These geometric modellers still suffer from the following:

- Incomplete database. Attributes which are required by the construction applications are not represented e.g. specifications, quantities, resources, etc.
- The geometry is stored in a very low level of detail which is not related to the construction processes. There are no higher level of abstractions of a project's description such as columns or walls. However, a number of software packages are now available to address this particular issue by providing a library of predefined objects.
- There are no query mechanisms in these systems, e.g. how many columns are there on the first floor?
- Similarly, in other domains of construction, where software is used as an aid tool, existing data that has been generated elsewhere has to be re-keyed by the user resulting in data duplications, multiple representations and transcriptions errors.

This limitation to the development and use of 3D modellers has created the need for an environment to facilitate the flow of project information between the construction applications. There is overwhelming agreement that this can best be achieved by the facilitation of data sharing and exchange in an integrated computer environment through a project model. The project model can be defined as a software representation of construction data which supports the project throughout its life-cycle. This approach enables project data to be effectively represented and managed over its life-cycle. The data could include anything about the project from the selling price to the way in which it was designed, planned, constructed, maintained and decommissioned.

3. THE STRUCTURE OF THE SPACE PROJECT MODEL

A framework has been established for the SPACE integrated environment with the aim of co-ordinating the integration process between the various construction applications. Project information is controlled and manipulated by a modularised project model from which all integrated applications can access their relevant information. The combination of all the data and process models which represent different views of the project participants in the modularised approach, represents the project model (Froese, 1995a, Froese, 1995b).

The model supports a wide range of construction applications. Currently it supports design, space recognition, element specifications, construction planning, site layout planning, estimating, valuation, maintenance and visualisation (virtual reality). In order to develop such a model, each of the above application domains has been assessed to identify its main data components and processes. The results of these evaluations have been mapped into data and process models using techniques such as EXPRESS-G (ISO, 1991), Object oriented methodology i.e. James Martin (Martin, 1993) and IDEF0. (The models were developed independently hence the different modelling techniques). This has made the models totally independent of any implementation tools. Further details on these models can be found in (Putra, 1998, Hassan, 1997, Faraj and Alshawi, 1996a, Alshawi and Suliman, 1995, Underwood and Alshawi, 1996).

The SPACE project model (Putra, 1998) supports different classes of data. These may be project specific, organisation specific or reference specific. Project specific data is that data which applies to a single project e.g. its fully defined geometry. Organisation specific data is that data which applies to more that one project e.g. resources, plant equipment which may be used on many projects. Reference data is a more general data, e.g. material properties. Figure 1 shows the approach adopted in SPACE to represent project information. It consists of an independent data model, an applications specific model and a project model.

The independent data model represents data that is independent of any particular application. It defines the entities that describe the building and the relationships that exist among these entities. The applications specific model defines the data that is relevant to support a particular application (e.g. construction planning and site layout). For example, a construction planning application requires data from the construction model (instance of the construction data model) to support the information required by the planning process such as generic construction activities, resources available, construction methods, etc.

The models are developed to complement each other and to maintain and share data in an efficient manner. In this approach, data related to a particular stage of the project life cycle is maintained separately from other data i.e. in the application specific model, but makes use of other data that exists in other models as and when required. For example, the construction planning data model contains generic information that describes the construction activities, methods, resources, etc. When the construction planning application is activated, it refers to the independent model, where information about the current project is stored, and to the construction planning model, where construction planning data is stored to generate the project's specific construction activities. The generated construction plan will then be part of the project model as it represents the construction process of one particular project.

The project model is the instantiation of both the independent data model and the applications specific models to represent all the data that is relevant to define the building elements.

In SPACE, the independent data model is mostly instantiated by software applications e.g. the building elements are captured automatically from CAD and the relevant part of the data model is populated. However, the user can overwrite this data by keying the information manually. At this stage, the independent model is partially instantiated. The application specific models, however, are instantiated either manually, e.g. the resources available, or automatically by the software applications, e.g. the generated construction plan. Each applications data model is responsible for generating a subset of the data which is required to satisfy a particular stage of the project life-cycle. If the generated data is required by other applications then it will be stored in the project model for ease of access.

This modularised approach enables the creation of a rich environment which is capable of serving existing and future applications. These models are implemented in SPACE, with the aim of testing the validity of the approach, using an Object-Oriented knowledge based system, KAPPA-PC (IntelliCorp 1999). This package was used because of its ability to implement data models rapidly.

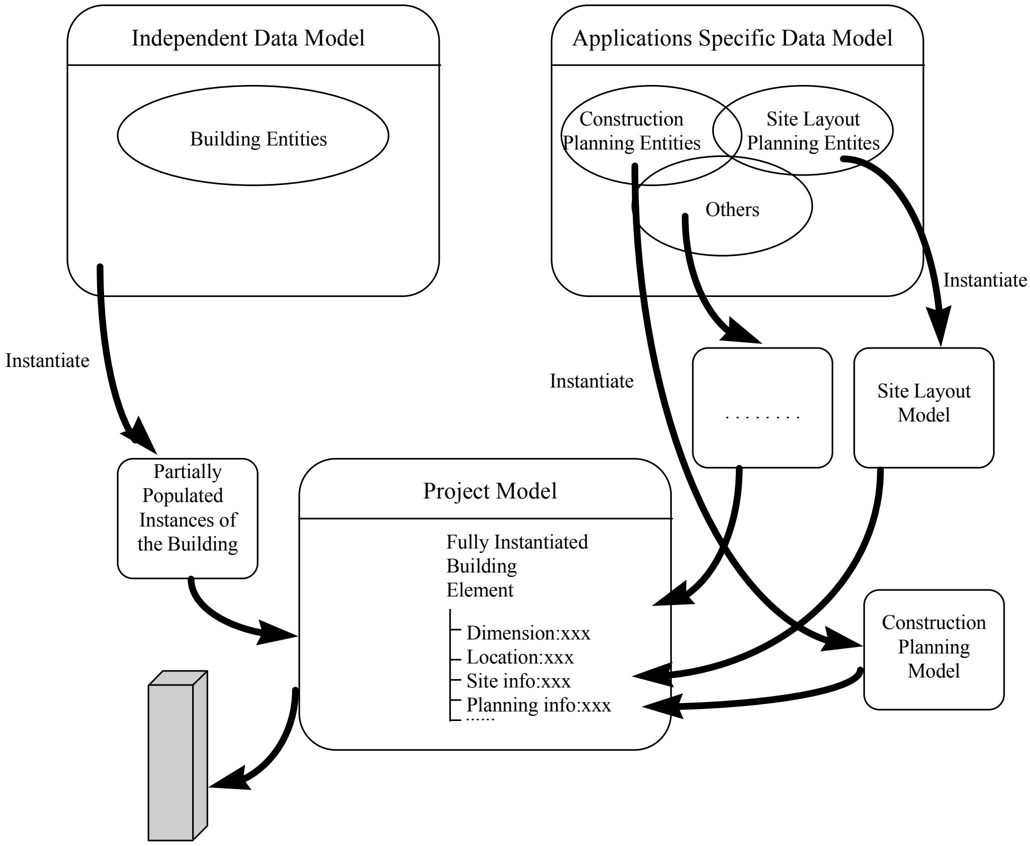


Figure 1: Project Model in SPACE

4. OBJECT RELATIONSHIPS

A building usually consists of a collection of different building elements such as walls, doors and windows. These building elements are normally introduced to the design from a library of building elements. Each building element consists of a number of low level geometric entities such as lines and arcs. This library can either be a commercial software or user defined. Most CAD systems do not capture the relationships and the type of interaction that exist among the different elements of the building. However, these relationships are important to a number of downstream construction applications such as construction planning and scheduling.

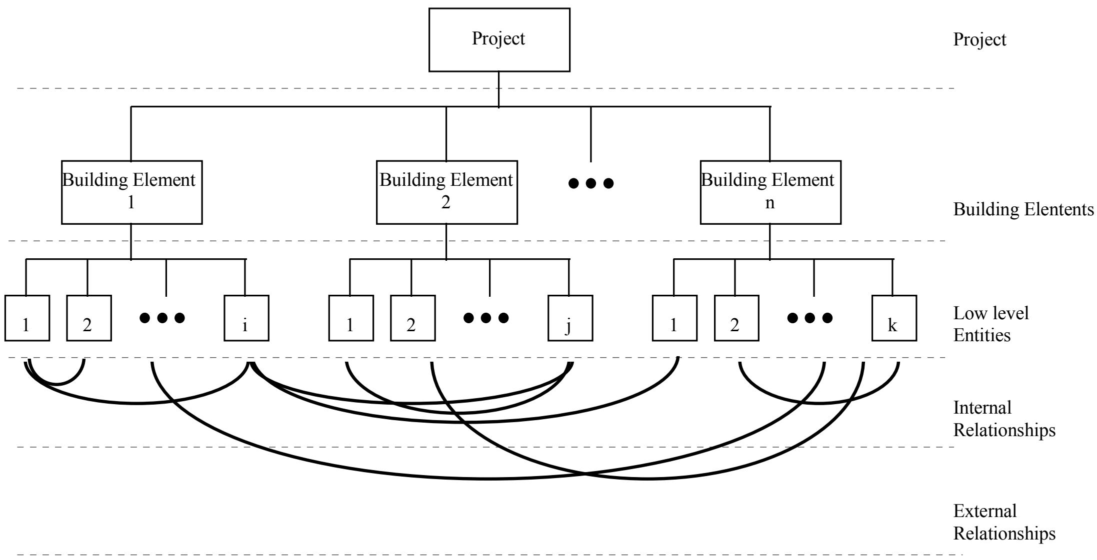


Figure 2: The hierarchical Building Elements Relationships

Figure 2 depicts SPACE, the relationship hierarchy of the building elements. Relationships are considered to be internal or external. Internal relationships are those which determine the identity of the element (internal wall, column, beam, etc) while external relationships are those which determine the relation between the various building elements (column supports beam, windows embedded in walls, etc.). If relationships between building elements (external relationships) are to be captured automatically by the applications software, the identification of the internal relationships that exist between the low level entities of each building elements must be established. In SPACE, the latter is performed automatically (Ewen and Alshawi, 1993).

The establishment of such relationships would enable the system to determine important information which is required by the construction applications. For example, these relationships can identify the spaces of the building automatically and the attachment of multiple values to one attribute (e.g. a wall can have multiple surface texture depending on the number of spaces it is part of). Figure 3 shows that one of the leaves of wall 1 is shared between space1 and space2, where different surface textures may be applied.

Different types of relations exist between building elements. SPACE supports the following:

- Supported-by: such as column and column, column and foundation, slab and beam, beam and column.
- Attached-to: such as wall and wall, wall and column.
- Embedded-in: such as window and wall, door and wall.

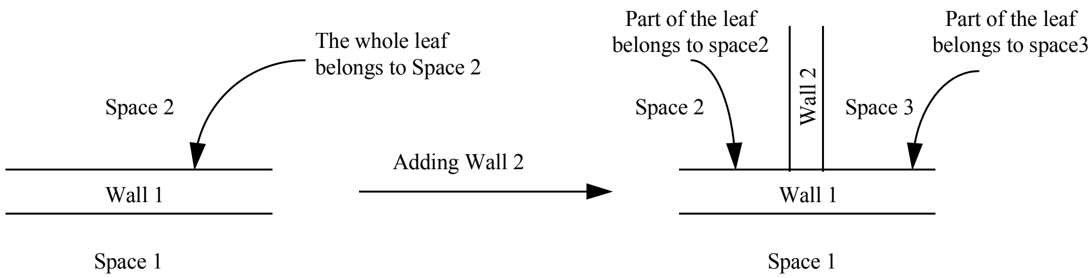


Figure 3: An example of a relationship between 2 building elements

5. THE IMPLEMENTATION OF THE SPACE PROTOTYPE

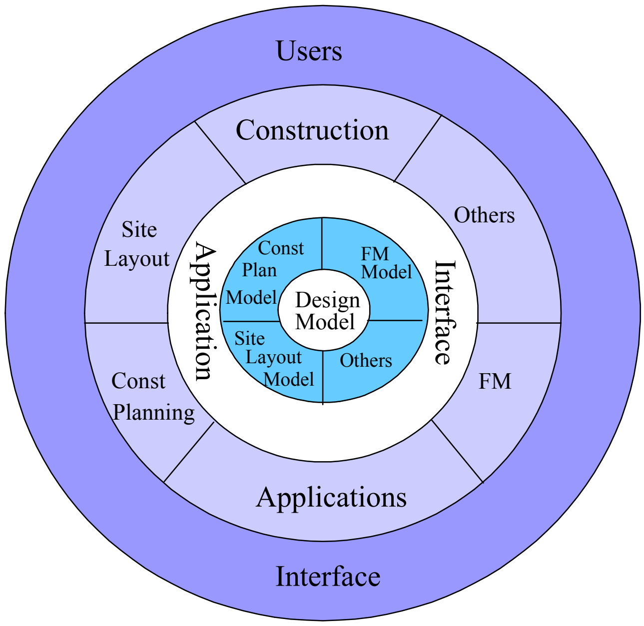


Figure 4: Approach to the Project Life-Cycle

SPACE takes an alternative view to the traditional design and construction approach, see Figure 4. It considers the project life cycle stages as applications which can be accessed simultaneously i.e. construction applications can be triggered off as and when required. This provides various users involved in a construction project i.e. clients, design team, contractors, planners, etc. with the opportunity to access the relevant project information at any stage. For example, clients can visualise the project in 3D and/or can examine whether the design solution meets their requirements and budget, while designers can investigate the impact of their design on construction thus giving them the opportunity to improve on the constructability of their design.

SPACE has been implemented in a modular structure, see Figure 5. It consists of a project model (implemented in KAPPA-PC) capable of representing all the data associated with a project life cycle. Each part of the project life-cycle is handled by a dedicated (application specific) model. Specialised applications software packages (e.g. construction planning, estimating, etc.) are interfaced with their corresponding application models for obtaining the required data. Each application model is supported by conceptual models, hierarchical object classes, methods/events/knowledge which are necessary to describe the model's behaviour at the implementation stage and its relationships with other application models and with the external world i.e. application software packages and external databases.

This modular approach gives SPACE the ability to run different applications on a number of computers if required. Various application models, whether the design model or the specific application models can be executed at remote sites and information is transferred from one computer to another through a communication media, such as networks or modems, see Figure 5. This will allow construction professionals to integrate through one project database.

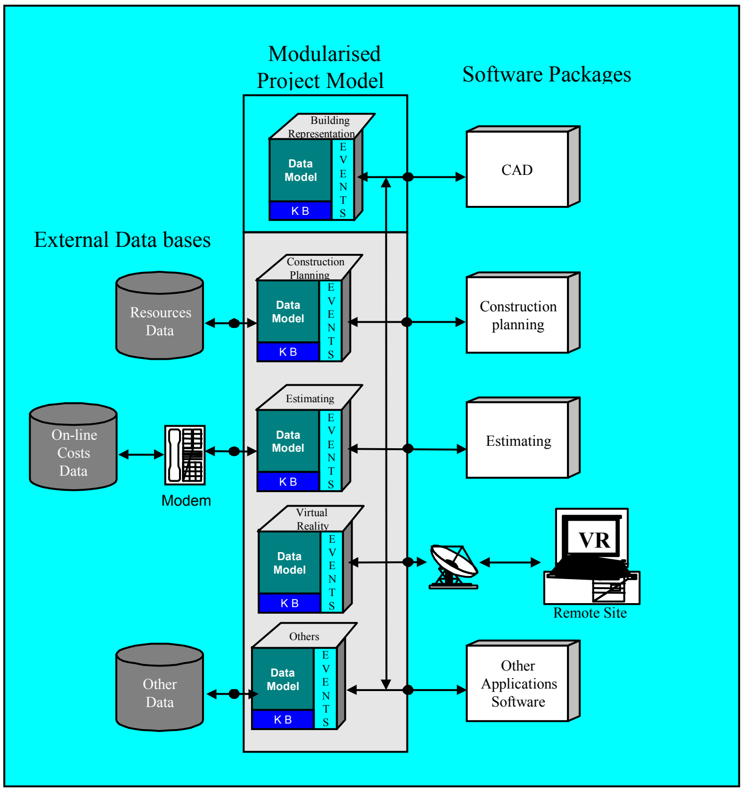


Figure 5: The Modularised Approach of SPACE

SPACE runs on a PC with Windows operating system. It uses a number of commercial software packages. These include AutoCAD/AEC (for design), World Tool Kit (for visualisation in virtual reality), Super Project Expert (for planning). These applications interact with the project model. Users can interact with the SPACE environment through a specifically developed system control, see Figure 6. The system control (developed in Visual Basic) is a high level control mechanism which enables the user to interact with environment and invoke the required application(s). It also enables the user to switch between the different applications at any time. All the applications can run simultaneously if there is sufficient data for these applications to be executed. Applications can request data and write newly created data to the project model if required.

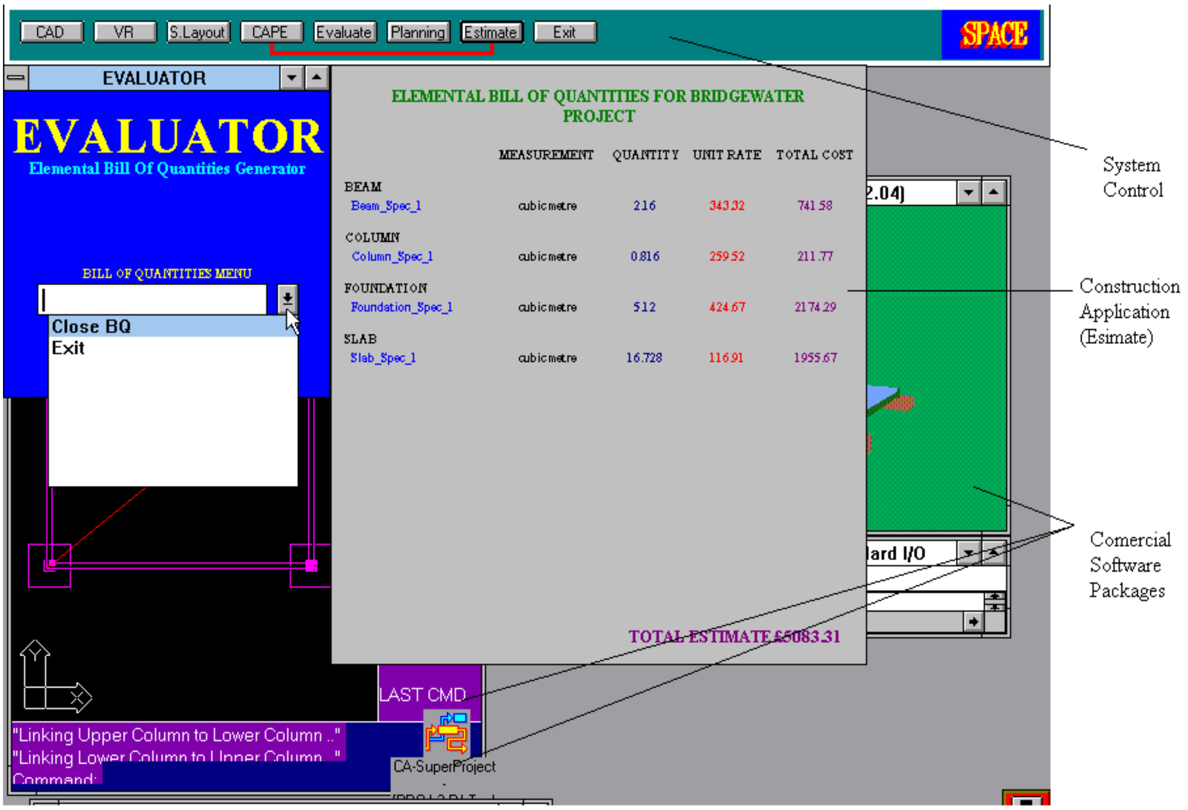


Figure 6: An example of the different components of SPACE

5.1 Instantiation of the Project Model

In SPACE, design information is transferred to the independent data model as and when generated. Once drawing primitives (low level entities) of a design element are converted to a high level object (building elements), the process of populating the object with data begins. Other applications also use this data to generate new data that is required during the project life cycle. This process continues until all the information required by the object, which enables it to serve all other applications over the project life, is satisfied. This process is highly dependent on the aims and the context of the integrated environment within which the objects are serving i.e. the developed construction application, the type of buildings, etc. Further information on object population over the project life cycle in SPACE can be found in (Alshawi et al, 1997).

In order to reduce the complexity and duplication of data, the data sharing principle has been adopted in SPACE. This enables objects that have the same specifications to point to one record. This eases the instantiation process and simplifies the modification of the specifications if required, as the user only need change the information in that record. For instance, it is not practical to duplicate the specification of every "column" instance if there is a large number of columns and if they all share the same specifications as this creates data management problems.

5.2 Objects Population in CAD

In SPACE, the process of converting the geometric low level entities into higher level objects, in CAD, and passing them to the independent data model is performed by the CAPE application (Construction Application Protocol for ComprEhensive data transfer) of which the building element data model is part.

CAPE is capable of recognising building element, identifying the element's relationship (internal and external), extracting the relevant information (dimensions and locations), classifying it according to functionality and relationship, identifying building spaces, and storing this information in a manner which is totally transparent to the user (Putra, 1998).

5.2.1 The system's Architecture of CAD link

The CAD link consists of three main parts, see Figure 7:
1. Object Interpreter Engine (OIE),
2. Object Creation,
3. Moderator.

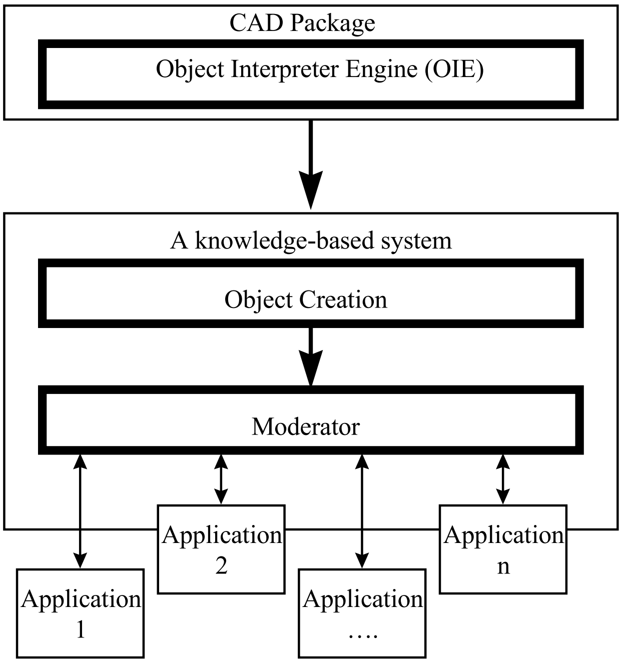


Figure 7: The CAD link in CAPE

1. The Object Interpreter Engine (OIE)

The OIE performs the following:
- *Creates the building element*. An element can either be created by selecting it from a library of elements (e.g. an "add-on" CAD package) or by using pre-defined blocks. The attributes of the element are usually entered manually by the user through an interface. In SPACE, the AutoCAD/AEC add-on has been used for the creation of the building elements.
- *Capture information from the created element.* Once the element is created, its low level geometric entities and the other relevant information are captured and stored in the project model.
- *Generating a graphical file*. A standard graphic file is created for each building element. These files can be used to exchange geometric information between applications. SPACE generates DXF (Drawing eXchange Format) files for every created element which can be accessed by the Virtual Reality (VR) application.
- *Check elements relationships*. CAPE automatically establishes the external relationships between the various elements of the building, as explained previously.
- *Perform space analysis*. This includes the identification of space boundaries and space separators. Once the elements have been recognised including their topological relationship with other elements, a space analysis is performed to identify the spaces that exist in the building and calculates the floor area of the bounded spaces and their volumes. This information is important for applications such as the calculation of heat loss and estimating.

2. Object creation

Object creation involves the instantiation of the project model class with the extracted object from CAD. The extracted object is then assigned a reference which is allocated to it by AutoCAD. This reference identifies each object uniquely and can be used by the applications to maintain the integrity of each object. Other applications are forced to access the objects through their references. Any changes to the objects will result in the propagation of the changes to the project model and hence to all the other applications.

3. Moderator

The moderator plays an important role in SPACE. It enables the construction applications to interrogate the project model. The moderator provides a mechanisms for applications to query the project model and provide answers to these queries in a manner that is readable by the application that initiated the query. It can also handle more complex queries by instructing applications to generate their parts of the answer and these parts are then restructured in a manner suitable for the application which has requested the data. For example, if "display the space boundary of the Living_Room" query is requested by the user, the moderator interrogates the project model obtaining the information on Living_Room. It matches the references (which identifies each building element uniquely) of the walls, floor and ceiling that bound the space against those building elements that exist in the design package (i.e. AutoCAD). It then instructs AutoCAD to highlight the space by drawing a dashed line encompassing the whole space, see Figure 8. Both the Object Creation and the Moderator are implemented using a knowledge based system.

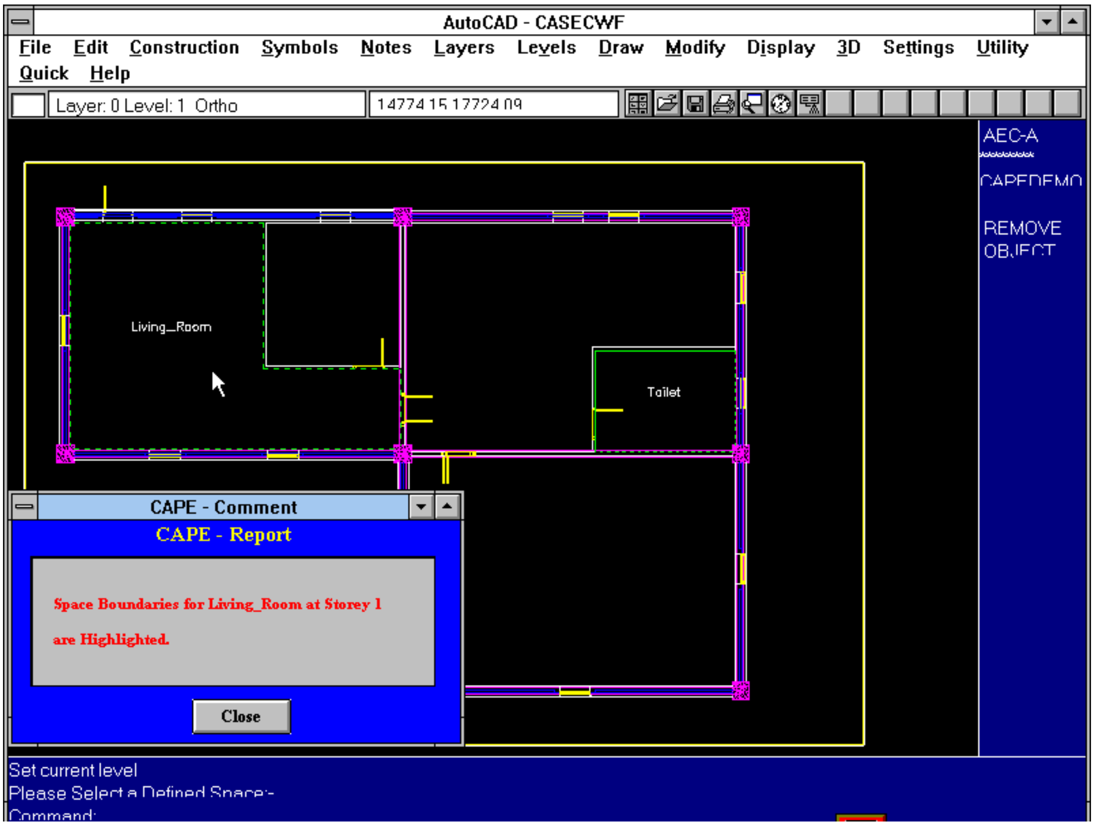


Figure 8: Example of space identification

6. SPACE SUPPORTED APPLICATIONS

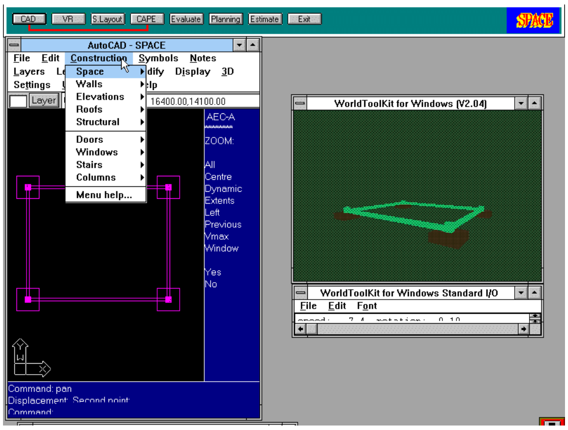
SPACE comprises a number of applications. Each application can run separately or concurrently and can exchange data with all the other applications via the central project model. There are 7 applications in SPACE. These are:

1. Specification definition and retrieval
2. Element recognition and design analysis (CAPE)
3. Construction planning and constructability analysis (CONPLAN)
4. Site layout (INTESITE)
5. VR representation (CONVERT)

6. Project estimate and interim valuations (EVALUATOR)
7. Maintenance (MAINCAST)

As a multimedia appendix to this paper, several demos can be downloaded from http://itcon.org/1999/3/demo/ . Then they must be unzipped and the resulting .exe file executed. The demos work on Windows. They are accompanied with sound, therefore a soundcard and speakers are required as well.

6.1 Specification Definition and Retrieval

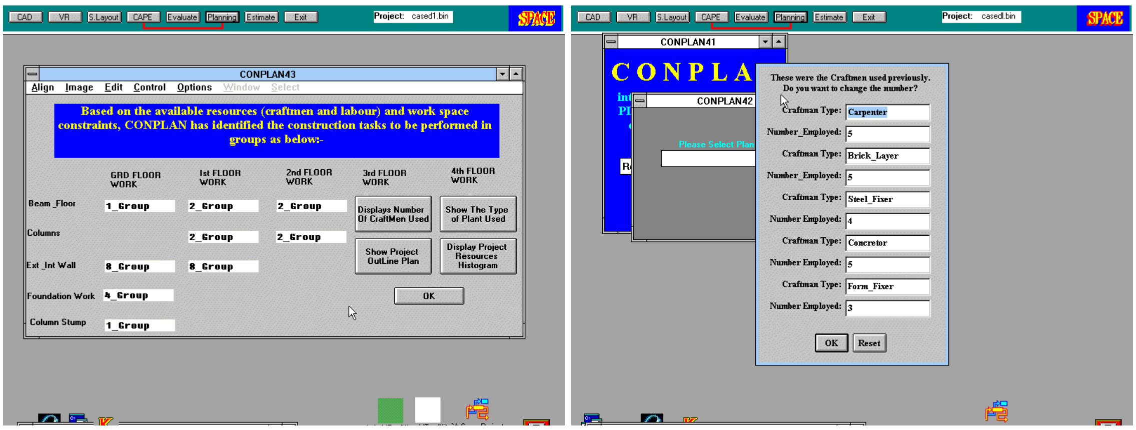


Demo 1: http://itcon.org/1999/3/demo/qckdemo7.zip (1.7 MB).

This application generates the specification for the design elements which CAPE has created from the AutoCAD drawing primitives. The specification application consists of a specification model which is linked to a number of external material/component databases. These databases have been developed based on WESSEX's cost database (Wessex, 1991). These materials/components external databases do not merely store cost information but also other relevant design information such as material strengths, thermal conductivity values, etc.

Once CAPE has generated the necessary information in the design data module, following the creation of an element or group of elements (of the same type) in AutoCAD/AEC, the specification for the/these element(s) is generated. The specification for a particular element is only created once in the Specification model, which is then referenced by all the elements with the same specifications. The individual components/materials for the specification are selected from the external databases.

6.2 Construction Planning and Constructability Analysis (CONPLAN)



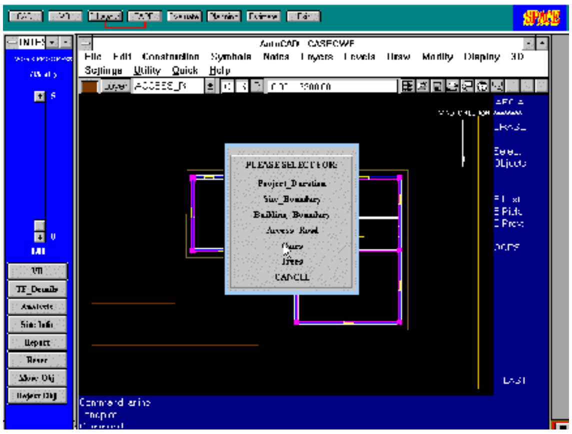
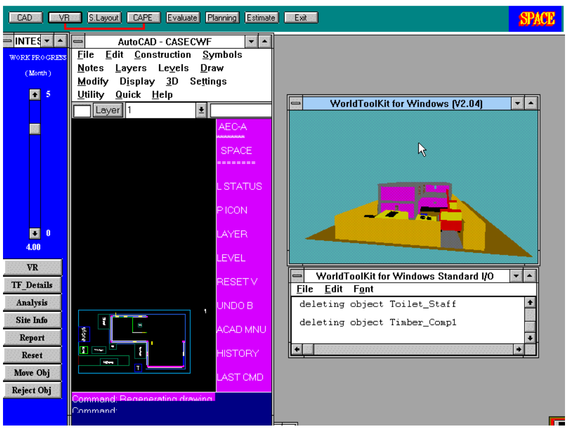
Demos 2 and 3: http://itcon.org/1999/3/demo/conplan3.zip (1.9 MB) and http://itcon.org/1999/3/demo/conrepln.zip (0.7 MB).

CONPLAN's main objectives are to dynamically generate construction plans of a project, based on the required activities and the availability of resources, and to analyse the construction activities, as derived by the construction plan, with the aim of identifying constructability related problems. Its independent model is supported by knowledge in the form of method and rules which enables it to respond intelligently to users' (contractors) requirements (Hassan, 1997).

Because this application is an 'event' oriented application, an object oriented analysis methodology (Martin and O'Dell) has been used. An Object Flow Diagram has been developed to model the objects along with their associated main processes. An event diagram has also been developed to model the various events that effect the entities involved. These models have been implemented as part of the SPACE project model. External databases have been used to store contractors' resources, methods, plant, etc.

CONPLAN represents a generic set of construction activities which can be allocated to specific design elements in order to generate a specific set of construction activities. Based on the available resources, construction methods, productivity rate, site spaces, etc., resources are allocated to activities and duration is calculated. Dependency between activities is also determined depending on the supported-by relationship, the activity's location, and the availability of site spaces and resources, etc. The application uses design and estimating data from CAPE and EVALUATOR to generate the construction plans in three levels of detail; detailed, master and executive. The construction sequence can be viewed in VR.

6.3 Site Layout (INTESITE)

Demos 4 and 5: http://itcon.org/1999/3/demo/sitelay2.zip (2.4 MB) and http://itcon.org/1999/3/demo/sitecons.zip (3.1 MB).

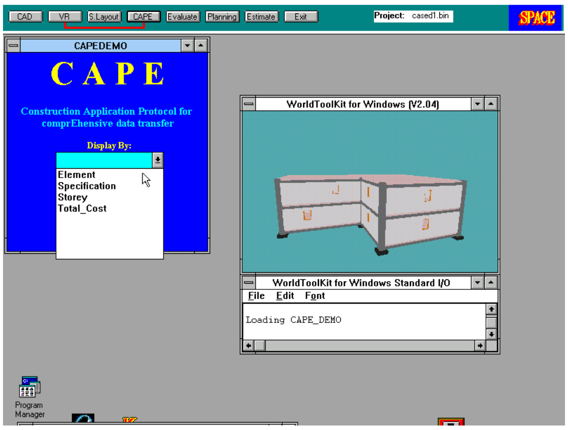
The main aims of this application are to dynamically produce site layout for a given design and construction plan which complies with standard regulations, safety, and productivity rules and to display and manipulate information in any graphical environment with suitable interface i.e. CAD or VR. Because this application is an 'event' oriented application, an object oriented analysis methodology, i.e. James Martin (Martin, 1993), has been followed. An Object Flow Diagram has been developed to model the objects along with their associated main processes. An event diagram has also been developed to model the various events that effect the entities involved. These models have then been implemented as part of the SPACE project model (Suliman, 1997).

INTESITE generates site layout through its integration with CONPLAN, CAPE and EVALUATOR. Information regarding duration, dates, materials, etc. is extracted from CONPLAN while information related to the design elements is retrieved from CAPE. This module creates the site geometry, i.e. boundaries, access roads and gates in the CAD environment and transfers them to its own module in the SPACE project model as objects.

The location of temporary facilities and relevant activities, at any particular period of construction, is determined and then displayed in a graphical environment, i.e. either CAD or VR. INTESITE also displays the stage of the building construction simultaneously with the site layout. Users can interrogate the graphical objects such as the temporary facilities, material, plant, etc. for more information.

The knowledge supporting INTESITE not only places resources in the best available spaces on site, but it is also able to comply with site regulations such as health and safety.

6.4 VR Visualisation (CONVERT)



Demo 6: http://itcon.org/1999/3/demo/cape1.zip (1.7 MB).

The main objectives of CONVERT are 1) dynamically generate a virtual environment that reflects a particular construction application view of the data, 2) generate a virtual environment in a manner that is totally transparent to users 3) display near to reality images 4) provide an interactive virtual environment, and 5) integrate with other future construction applications (Faraj and Alshawi, 1996b, Faraj and Alshawi, 1996c).

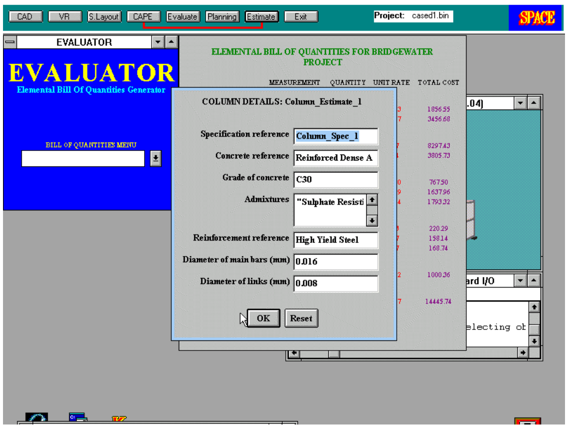
CONVERT interacts with all the six application models. The IDEFØ technique has been used to model the interaction of all the applications within SPACE. These models have established the principles of CONVERT implementation.

CONVERT is capable of building a virtual environment of the design and other construction applications, including the simulation of the construction activities. The system interacts with design and other application specific application models to obtain all the data needed to generate the virtual environment that corresponds to the application's view of the data. It also maintains the integrity of the design in the virtual environment by maintaining the relationships that exist between objects in the project model. CONVERT, which is supported by the project model, enables intelligence to be incorporated in the virtual environment and makes it possible to obtain any information about any object, write newly generated data back or updated data in the project model.

6.5 Project Estimate and Interim Valuations (EVALUATOR)

The EVALUATOR splits into two applications, the objectives of which are to: (1) generate the project estimate from the design drawings in the form of an elemental BQ (together with all-in-one rates) and (2) automatically produce interim valuation for monthly payments from the construction plan. The data modelling technique of Express-G has been used to develop the data model, while the process model has been created using the IDEFØ technique. Both models have consequently been mapped and linked into the SPACE central repository project model (Alshawi and Underwood, 1996).

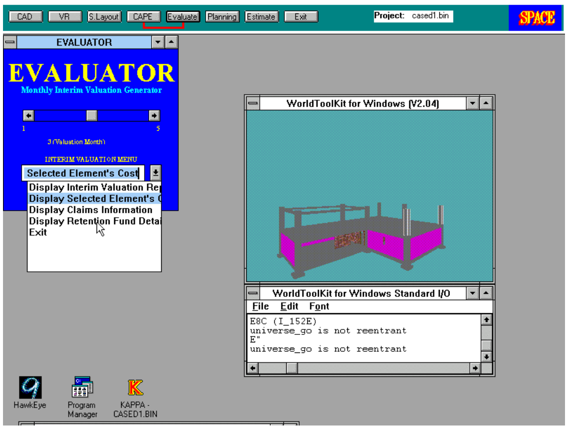
6.5.1 Generating the Project Estimate



Demo 7: http://itcon.org/1999/3/demo/estdemo1.zip (0.7 MB).

EVALUATOR generates the project estimate via its integration with the CAPE module and the construction planning module (CONPLAN). Information from the CAPE module such as the design elements, their dimensions, specification, associations with other elements, etc. is accessed by EVALUATOR. Material costs for the design elements are first determined. Secondly, their construction costs are calculated from information provided by the construction planning module. All-in-one rates are then generated from both materials and construction costs, thus leading to the development of the elemental BQ. Further integration between EVALUATOR and the VR application (CONVERT) has also been developed which enables users to interrogate EVALUATOR in virtual space, i.e. in a near-to-reality representation simply by interacting with the representations of the design elements in the virtual space.

6.5.2 Generating Monthly Interim Valuations

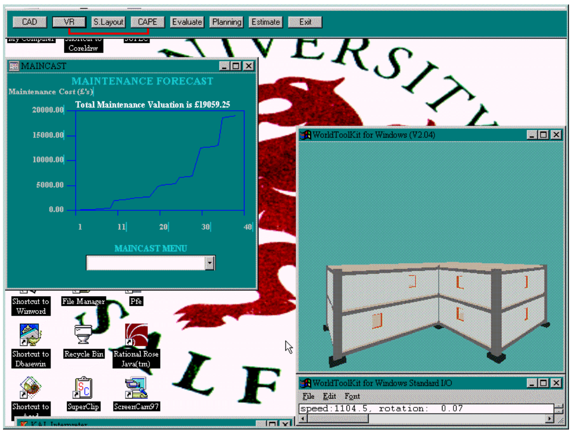


Demo 8: http://itcon.org/1999/3/demo/valdemo2.zip (0.9 MB).

Monthly interim valuations are generated based on the information produced by the construction planning module. Information such as the start and finish dates of activities, the design element associated with an activity, etc. enable EVALUATOR to; (i) identify the activities relevant to the particular valuation month, (ii) determine at what percentage each relevant activity is complete and (iii) identify the fully or partially completed elements during each valuation (Underwood and Alshawi, 1997a).

From the completion of (i), (ii) and (iii) together with the project estimate, the valuation is subsequently produced. However, before the valuation is processed, an interaction between the Interim Valuation Module and the VR application (CONVERT) initially displays and highlights the fully/partially completed elements for the respective month in virtual space. This gives the user the opportunity to enter the variation orders for the constructed elements by selecting the relevant elements in VR and the variation orders for new items. In the case of a new item being entered, a new rate is built-up. Finally, once the interim valuation report is generated, the textures of the highlighted elements in VR are reverted back to display the current state of the construction at the end of each valuation month.

6.6 Maintenance Forecasting In An Integrated Construction Environment (MAINCAST)



Demo 9: http://itcon.org/1999/3/demo/mntcdemo.zip (0.8 MB).

The principal tasks of MAINCAST are to automatically identify the necessary maintenance at annual stages in the project's operational life and to examine the effect of any changes to the design (project information) on maintenance. The data modelling technique of Express-G has been used to develop the data model, while the process model has been created using the IDEFØ technique. Both models have consequently been mapped and linked into the SPACE central repository project model. (Underwood and Alshawi, 1997b).

MAINCAST is fully integrated in the SPACE environment. It automatically calculates the maintenance forecast over the project's operational life before displaying it in the form of a X-Y graph, i.e. cumulative maintenance valuation against maintenance year. The user can select to display the maintenance valuation for any of maintenance year. The displayed maintenance valuation presents the cumulative maintenance valuation up to and including the selected year, the total maintenance valuation for the selected year, together with a breakdown of the individual remedies and their associated costs. In addition, the building elements that require replacement and repair maintenance during the selected maintenance year are highlighted within VR (such that they are instantly recognisable and distinguishable between replacement and repair maintenance). The user can also interrogate the building elements from within VR. By selecting one of the highlighted elements, the remedy and the cost of the remedy to the individual element is displayed. However, should the user select an element that is not highlighted, then MAINCAST will display the element's next expected maintenance, the time (year) at which this maintenance should be carried out, and its cost.

7. CONCLUSION

This paper has presented an overall view of a rapid prototyping environment, SPACE. SPACE has adopted a modularised approach to represent project information using an independent data model and construction specific data models. This approach enables future expansion of the environment by developing and integrating applications with the current structure without affecting the existing applications. The independent data model is mostly instantiated by software applications e.g. the building elements are captured automatically from CAD and the relevant part of the data model is then populated. The application specific data models, however, are either instantiated manually, such as in the case of the resources available, or automatically by the software applications, such as in the case of the generation of construction plans. Each applications data model is responsible for generating a subset of the data which is required to satisfy a particular stage of the project life-cycle.

The approach has successfully been implemented in a prototype system that demonstrates the representation of project information and the sharing of data and interaction among the various supported applications. The outcomes of the applications are further enhanced by providing an intelligent support to each of the supported applications. The prototype was tested with a number of case studies provided by industry.

Future applications can be added to SPACE. However, prior knowledge of the data models is necessary before they can be successfully integrated. Another problem is the upgrade of commercial software which may necessitate the upgrade of the application that use them. This problem will be alleviated with the development of international standards such as the Industry Foundation Classes (IFC) where software packages are expected to be compliant with such standards.

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