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The application of a knowledge based engineering approach to the rapid design and analysis of an automotive structure

Craig B. Chapman*, Martyn Pinfold

Warwick Manufacturing Group, Advanced Technology Centre, University of Warwick, Coventry CV4 7AL, UK

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Abstract

This paper describes a knowledge based engineering system (KBES) to extend the current capabilities of automotive body-in-white (BIW) engineers. It allows them to respond dynamically to changes within a rapid timeframe and to assess the effects of change with respect to the constraints imposed upon them by other product cycle factors. The system operates by creating a unified model description that queries rules as to the suitability of the concept design and is built using a standard KBES to reduce project costs and system implementation. Knowledge from expert engineers and technical literature are captured and represented within the KBE application framework. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Knowledge based engineering; Computer aided design; Finite element analysis; Meshing; Design automation; Automotive application

1. Introduction

The use of computing technology in the design and analysis of automobiles has been developing at an increasing rate. Such systems are currently used piecemeal and provide solutions to very specific problems. Understanding the vast amount of data and managing its flow through complex systems is extremely difficult without an integrated systems approach. One such approach is the use of knowledge based engineering (KBE) techniques as a way of organising the data flow and as architecture for the effective implementation of automated variant design solutions. A specific challenge is the integration of concept design tools to allow the rapid development of structural design solutions within the body-in-white (BIW) automotive area while supporting existing analytical solutions.

BIW is an automotive term used to describe the structural body of a vehicle. The structure is comprised of many sub-structures that come together to form a framework. The framework has a number of functions such as distributing the structural load and providing a level of safety in the case of impact. External environmental legislation is forcing automotive manufacturers to minimise body weight. The BIW represents the heaviest singular component that has the largest influence on many of the vehicle characteristics. Design effort to optimise material usage and improved construction methods has lead to the use of mixed material structures. More design effort and time will be needed to ensure the optimum design for this wider range of options. This in turn requires a faster method for concept structure design in order to avoid the lengthening design and development programmes for these hybrid material body structures.

This paper describes the design analysis response tool (DART) created to aid in the design/analysis of a BIW structure consisting of structural beams, jointing methods and body panel creation.

2. The BIW design analysis problem

An integral part of the BIW structure design route is the analysis of components or assemblies using finite element (FE) techniques. As illustrated in Fig. 1, the design analysis procedure may be broken down into four distinct phases: product modelling, pre-processing, analysis and post-processing.

In order to accurately analyse the computer aided design (CAD) geometric product model and recognise it as a real world entity, additional non-geometric information is required by the analysis process. Thus, material property data is attached to the model and the model subjected to forces, stresses and strains. In FE analysis, the model is broken down into a large number of interconnecting FEs

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* Corresponding author. Tel.: +44-24-76-524-721; fax: +44-24-76-524-783.

E-mail address: c.b.chapman@warwick.ac.uk (C.B. Chapman).

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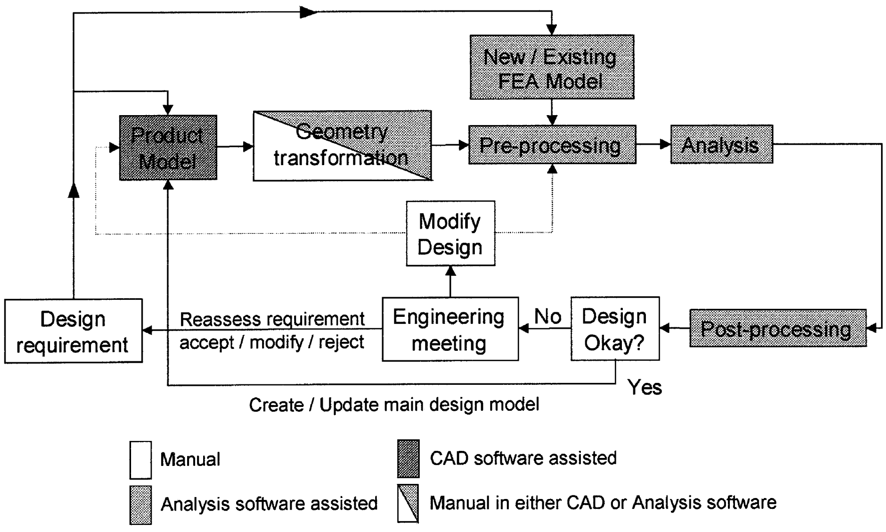

Fig. 1. The design analysis loop.

that form an appropriate mesh, each element knows its material, mechanical and thermal properties. This information allows the prediction of the resultant effect of loads at particular points in the model. The analysts then use their experience to interpret the results and make suggestions to the designer, who then makes the necessary manual changes to the original model. Currently, in the traditional BIW environment the design and analysis stages are de-coupled as they are undertaken by different experts utilising different computer softwares and creating separate non-relational product models. Once changes have been agreed the engineers refine their individual models and the analysis–modify loop is entered into again until a satisfactory result is obtained.

Most authors [1–3] agree that the most time consuming part of undertaking an analysis is the pre-processing, i.e. the creation of the analysis model, as the models created in CAD systems have to be processed to ensure that they are in a suitable form for meshing. As Jones et al. [3] state the geometric model created in a CAD system can be incoherent and ambiguous and "may require significant cleaning and modification in preparation for meshing and analysis". To avoid these problems analysts may create their own model from scratch [3,4]. The creation of a model for analysis involves importing the model in the form of a neutral file format from the (CAD) system. Alternatively, in the case of the CAD and analysis system sharing the same data base structure, the analysts use the CAD model to make the necessary changes and then store the model to the data base as a new model. This leads to the analyst creating a totally new model within the analysis software package. All these present strategies lead to model duplication. Once the model is correctly represented within the analysis environment, materials and loading conditions are applied and a mathematical mesh representation created. This is time consuming as although some systems have developed automatic meshing routines, they as yet still require time consuming manual modification to create optimum localised conditions within the model. The next phase of the actual analysis requires the analyst to run the analysis program. This is normally done in batch mode, in which the job is submitted to the computer to run automatically in the background or overnight. The final phase is post-processing or the interpretation of the results. The system presents the results to the analyst who verifies or suggests changes to the design model. The results generated are one of many factors that aid the engineer in determining the feasibility of the original design or in further optimisation and redesign strategies.

The need to consider a number of different alternatives at an early stage in design has been well established. A tool for automatically modelling and analysing the behaviour of a design would aid the designer by providing the facilities to consider more varied alternatives. In many cases within a company the geometry, FE mesh and boundary conditions for the analysis are generically essentially the same for many generations of components. Currently any geometry of such a structure provided by a CAD system to an analyst has to be simplified before the creation of an FE mesh and subsequent structural analysis. This simplification and mesh creation process can be very time consuming, Desaleux and Fouet [5] state that the costs for the creation of an FE mesh represent about 80% of the total analysis cost.

The BIW group although existing at present as an island of automation was required to interface with both upstream and downstream clients in the product cycle. These clients imposed constraints that had to be adhered to. Upstream clients such as styling and packaging imposed an outer surface definition (OSD), areas of attachment and also no-go areas. A structural member's position may be optimised, but if were to pass through an occupants body there would surely be complaints. The downstream clients such as manufacturing need to take the developed structure within their CAD systems and develop a fully detailed vehicle representation, at present the data structure of the FE modelling software prevents this. BIW design can be seen as a routine or variant design problem, as the same generic problem is faced over and over again, the design requirements are understood, including the knowledge needed but the specific design solution and the pattern of use of the knowledge is not repetitive. This type of problem lends itself to automation by the use of a KBE system [6].

2.1. Problem summary

1. The present methods of using CAD and finite element analysis (FEA) systems do not use a unified product/process model representation and lead to the creation of separate non-relational data models that only capture the result of the engineering process.
2. The present methods do not automatically transform or simplify the model to suit the specific process request.
3. The present methods do not automate the meshing process with respect to 'best-practice' guidelines, material or assembly considerations.

3. The solution

The BIW engineers experience is used to develop a body structure concept consisting of beams, joints and panels to satisfy the vehicle requirements with respect to strength, durability, stiffness, low frequency vibration and crash. To save time, existing FE models that closely represent the type of structure required called donor cases are looked into and modified to suit, within the analysis software packages. If the vehicle were of a new type that did not suit using a past case then a new concept structure would be developed within the analysis package. It became clear through discussions that if the current situation were to improve then the way of working must change. It would be necessary to move away from a progression of simplified to detailed meshed models created directly within the analysis software and that could not be used directly by the other product cycle clients to a modelling environment that could satisfy the needs of all the clients.

By taking a holistic approach to BIW design that meets this need, we needed to create a free form three-dimensional feature based environment that would provide a concept area where the engineers could bring in past models or create new structural models rapidly. These structural models then needed to be verified with respect to the style, packaging and manufacturing constraints. In the final stage, the model needed to automatically transform into the representation required for whichever product cycle client requests it, based on in house best-practice knowledge. Capturing the best knowledge from the multidisciplinary teams helps to reduce concurrency barriers that exist in today's process. It was felt that the key to the natural integration of such systems into the BIW area must lie in the fact that any system can be created utilising traditionally understood concurrent engineering (CE) methods and be modified and used readily by the workforce in the domain area without necessitating the use of additional resources, which are only specifically focussed on one area of a system development.

3.1. Concurrent engineering

CE allows the engineering team to utilise the varied inputs, knowledge and technology to speed up product development by integrating product cycle concerns as early as possible in the design process, by performing simultaneously many activities that used to be performed in sequence [7]. For CE to work, the agents in the product cycle need to be integrated with respect to appropriate information exchange. For the purpose of creating an integrated design environment, computer tools are used to complement and assist the multidisciplinary team, giving the ability of each member to access a common product model data structure. Using today's traditional CAD tools and the reliance of geometric modellers to provide representations necessary to create a high degree of parallelism in the design process is unlikely to succeed [8]. Most research focuses on one or a small number of product cycle activities [9] and the more abstract design activities such as the capture of functionality, conceptual design and the generation of design alternatives, reuse and reasoning are just impossible [10]. To overcome these limitations set by the traditional design tools, we are now seeing a revolution in design, one where the knowledge of the actual process is being represented. The specifications are being transformed into sets of attributed objects that act together to satisfy the specification. We are also seeing the role of the human/computer interface changing, where the system takes a more active role. The interface allowing human ideas to be externalised and the limited inference abilities of the design tools are being increased to interpret and assess the impact of any change to the product cycle model. One of the methods being used and researched to acquire, represent, store, reason and communicate the intent of the design process is KBE.

3.2. Knowledge based engineering

KBE represents an evolutionary step in CAE and is an engineering method that represents a merging of object oriented programming (OOP), artificial intelligence (AI) techniques and CAD technologies, giving benefit to customised or variant design automation solutions. KBE systems aim to capture product and process information in such a way as to allow businesses to model engineering design processes, and then use the model to automate all or part of the process. The emphasis is on providing, informational

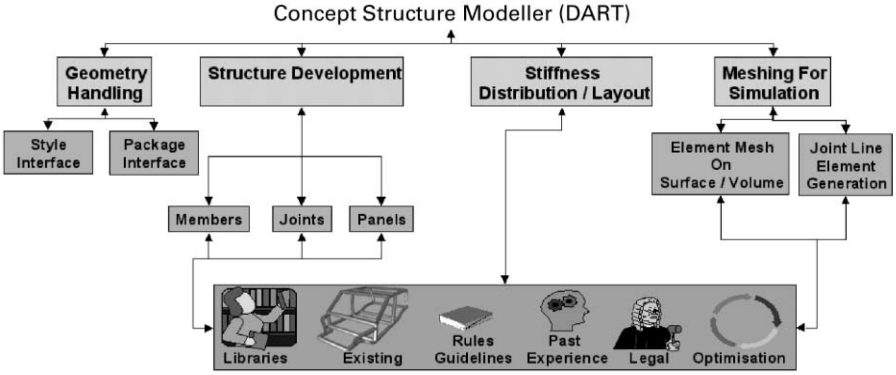

Fig. 2. Initial basic layout.

complete product representations, captured in a product model. The product model represents the engineering intent behind the product design, storing the how, why and what of a design. The product model is an internal computer representation of the product design process and can contain information on both the product and processes that go to create the part. Attributes can describe geometry, functional constraints, material type and processes such as the methods required to analyse, manufacture and cost a part. The KBE product model can also use information outside its product model environment such as databases and external company programs. The ultimate goal of the KBE system is to capture the best design practices and engineering expertise into a corporate knowledge base. KBE methodology provides an open framework for formally capturing and defining the process of design creation within a system that can infer and then act on this information [11]. There have been many examples of KBE being successfully used to model products that require knowledge from various design cycle activities and represent themselves based on the varying activity perspectives, such as Textron Aerostructures who announced the deployment of a tooling design application that delivered a 73% reduction in design time [12]. Boeing has published that approximately 20,000 parts for the 777 aircraft have been designed using KBE [13]. The use of KBE within the British Aerospace sector has lead to cases such as the BAe Airbus Rib Foot KBE application which when using Parametric CAD and analysis tools took on an A340-600 aircraft 1 man year to design and analyse all the rib feet once. Using KBE and using a holistic approach the entire A340-600 wing is done in 10 h [14]. A number of papers have been published by the US Air Force Research Laboratory [15–19] which discuss the development of a structural modelling tool using KBE techniques to address structural concept designs of a uninhabited combat air vehicle (UCAV). The papers concentrate on the design of a wing with the KBE environment being used to integrate the model with various analysis programs such as ASTROS FE analysis, an activity based cost model and a commercial optimisation algorithm called design optimisation tools (DOT). The input data deck for the ASTROS analysis is created within the KBE environment. Once ASTROS has been used to create an optimal structure the cost model, which is based on a preliminary level manufacturing analysis, is used to determine both one time and per piece costs for producing the wing design. The research [19] reports that the program developed significantly reduced the time to create the ASTROS FE models.

3.3. Implementation

There have been many development methodologies suggested for the KBS domain, such as KADS [20]. These methodologies have been aimed at assisting the developer define and model the problem in question. Successful commercial KBE developments have not followed these routes as the methodologies are felt not to be flexible enough to model the dynamic design engineering environment. Work carried out by the MOKA Consortium (methodology and software tools oriented to knowledge based engineering applications) recognises the deficiency in dynamic methodologies specific to the KBE domain [21] and aims to provide the KBE community with a working implementation/development methodology. The flexible nature of KBE tools does not dictate a particular implementation or development approach. However, many applications follow a similar pattern, that of a normal design-engineering problem. The only difference being the use of a KBES language to implement the desired solution and due to the object-oriented nature of KBES and the use of rapid application development (RAD) programming techniques. The process of incremental development accomplishes implementation.

The first step is to state the problem. Full definition is not required as the prototype model is often used to ‘bring out’ full and open discussions between all personnel involved in the product life cycle. The DART initial specification and project requirements were gathered by using standard CE methods, consisting of initial meetings to understand the problem, focussed interviews with relevant engineering staff, the iterative creation of solutions (paper based) and open brainstorming meetings bringing about focussed

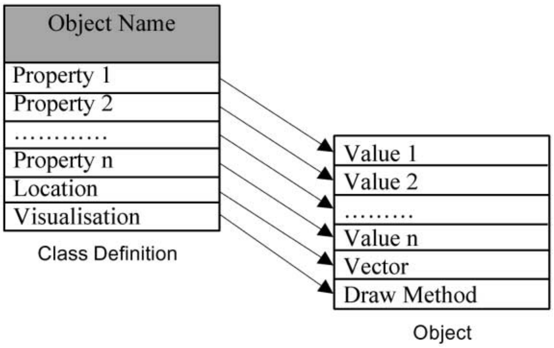

Fig. 3. Class and object relationship.

agreed actions between all product-cycle concerns. Treating the project as a normal engineering problem solving exercise meant that all people involved in supplying rules and defining the system had the necessary skill sets. The CE team meetings were held over a period of time until a system requirement and initial layout was established. The requirement was agreed as follows.

The concept design system will use the specified structural performance and overall dimensions to establish an appropriate stiffness distribution within the constraints of the initial style and package. It will then use relevant structural, manufacturing and material knowledge to create an initial concept body structure. The structural performance of this design will be assessed using FE simulation, for which the system will generate appropriate FE models and analysis input data. For the evaluation of the effects of modifications on the structural performance the system will revise the design in accordance with any geometric changes which the designer makes, and generate updated analysis input to re-evaluate its structural performance within a timescale needed to support the design decision processes. The tools will be developed for use by structural analysts and body concept engineers, see Fig. 2.

After stating the problem and identifying the information required by the model, key objects were created, to form a parts library. As each of the part objects was defined, they were individually tested, by creating an instance of the object. Part objects created within the KBE system form the building blocks of any model, often representing real world objects. The DART model breaks down into six main parts the style, packaging, structural members, joints and panels. These parts then decompose further, each stage of decomposition varying the intelligence of the objects. For example, primitive objects might only know how to draw themselves, whereas higher level objects will use the knowledge base to make specific decisions regarding their shape, relationships, manufacturing process and cost.

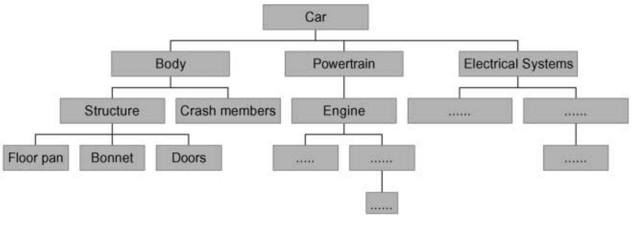

Fig. 4. Product model tree.

Part object terminology changes depending on the application domain. As most KBE systems are based on OOP methodology, they solve problems by defining, creating and manipulating collections of data and procedures called objects. The terminology and concepts behind OOP and KBE relate to how objects are defined, have properties assigned to them, how they interact and how they are combined to form more complex objects.

The object encapsulates the data or properties, and the methods to manipulate that data into a single unit. The class is the template, and the object is specific case, (Fig. 3). An object with a particular set of values is called an instance, of a class definition.

When values change that are used by the object to calculate properties or as parameters for method procedures, the object is re-evaluated. This is called demand driven computation and is a fundamental difference between OOP and conventional procedural programming. It is typical that any change made to a procedural language or CAD/CAM macro language will result in re-computing everything, since the computations are performed in sequence. In a procedural language a value is computed when the procedure for computing it is encountered in the sequence. In KBE systems, values are computed only when required. This technique is called dependency backtracking. For example if the topology changes, the model will not be recomputed until a request is made to draw the object on screen, or a calculation for the changed objects mass properties are made.

The method of creating objects is very similar in most commercial KBE systems. The adaptive modelling language (AML) from TechnoSoft [22] used within this project has the ability to create objects and write rules from templates that assist the designer in writing the programme. The object or define-class form is used to define new classes. In any define-class, the following may be specified:

1. Other classes which the new class should inherit from (superclasses).
2. The properties for the new class and their formulas (attributes).
3. The sub-objects of the new class (children).

The next step was to create an initial conceptual product model. This is not a complete representation, but acted as a first draft, a blueprint of the implementation. The conceptual product model can be thought of as a schematic of the completed system. A product model tree (Fig. 4) describes a particular design instance of a product model. This structure describes the hierarchical relationships between the

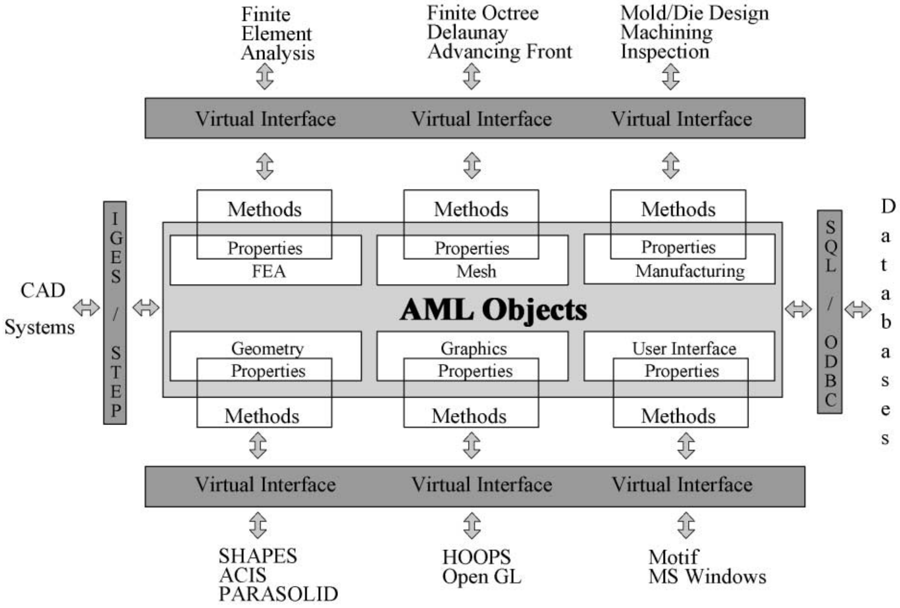

Fig. 5. AML virtual layer architecture [22].

various components (parts and processes) of the model. The model also determines the methods of how the objects will obtain the correct information, in order to carry out their specific tasks and as to the information they will provide to other objects. This hierarchical abstraction means the decomposition of information into levels of increasing detail [23,24]. The decisions made by the system to create a model will be based on the user inputs and the knowledge bases.

Using the initial part library and conceptual product model as a starting point, a subset of the overall system is defined, complete with user interfaces (UIs). The system is extended by increasing the part library, UI and by expanding the object class definitions. The incremental RAD development approach means that the system can be continuously evaluated and utilised as it is always operational.

3.4. Rapid application development

Building KBE systems within the iterative design environment has lead to the use of RAD techniques being employed, by KBE developers. A typical system will evolve over time. Akman [23] suggests that the strategy, in the development of an intelligent CAD system, should be to “Plan to throw one away. You will anyhow”. The nature of design is an exploratory adventure within a set of possibly conflicting constraints. The techniques of RAD are complementary to the designer’s natural way of working, RAD is in fact exploratory programming. The techniques advocate iterative programme enhancement, leading to an evolutionary life cycle. The KBE system starts with a skeletal system, with new modules added until a review stage is entered into. From the rapid prototype demonstration, the strengths and weaknesses are assessed and the program developed further.

There are some development process differences in that the process is not entirely sequential, key parts of the development occur simultaneously [25]. The developer sequentially works from system analysis through design and programming to testing, and finally ends up with the product. Changes are made to the system design at the appropriate level, rippling down to the rest of the program. The developer then changes the code and retests the system. With RAD, the developer designs and prototypes the component parts separately. This type of technique allows teams of engineers to work in parallel.

3.5. Hardware and software

To develop the system a Silicon Graphics R10000 and a P400 PC running Windows95 were purchased. A number of commercial KBES were assessed for project feasibility. The system needed to run independently on both UNIX and PC platforms and its commercial cost needed to be below the allocated project budget costs of £75,000 when included with the computer hardware. It needed to have an open architecture (Fig. 5) with easy interface creation, knowledge capture methods and geometric reasoning capabilities. The AML from TechnoSoft was selected as the most cost effective solution and provided a KBE framework that allowed the capture of knowledge from the modelled domain and the ability to create free form parametric models with that knowledge. To meet the analysis requirements a PATRAN and an ANSYS license were purchased.

4. The design analysis response tool system

The DART application is designed to allow the BIW engineer to interact through a set of menus and graphical

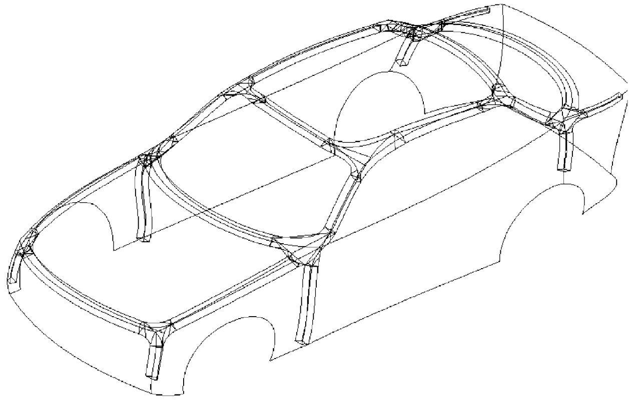

Fig. 6. Frame structure around style model.

interface tools, to rapidly create a BIW space-frame structure with panelling in a three dimensional solid/surface representation. The model can be created in a non-structured way with material and target stiffness information added at any point in the modelling session. Structure sub-parts such as beams, joints and panels can be modified in real time without consideration of the analysis requirements. At any point within the design session, the engineer has the ability to simplify the design model automatically for input to analysis. The concept structure can be verified at any point within the session with respect to manufacturability styling and packaging conflicts.

4.1. Vehicle surface model and packaging

The initial input to the DART structural process, is the specification of a vehicle OSD. This OSD forms the outer working constraint to which the BIW structural package must adhere to and meet all its functionality. Secondary attachment and 'no-go' areas are defined by the importing of packaging objects, for example mannequins and powertrain components. The system was developed to enable the specification of the OSD using:

- Imported data via standard format such as IGES, STEP, (style and packaging).
- The specification of structured point data sets, defining the OSD surfaces and edges boundaries, (style only).
- The import of models via native CAD database formats, e.g. Parasolid and Shapes, (style and packaging).
- The import of previously stored models retrieved from the object database, (style and packaging). This provides a rapid response to the analyst if changes late in the development programme have occurred, such as packaging alterations that will force modification to the assigned structural members.

If a model was not available at this level of concept design the system allows for the structure to be defined without reference to an initial OSD.

4.2. Frame structure design

This task addressed the various issues related to the design of the structural frame. These issues dealt with the specification of the various structures members centre curve, cross-sections type, shape constraints, interference checking and interference avoidance. The creation of the structural frame design addressed the issues related to the design of the structural beams, the frame interlocking joints, stiffening and joining panels. Issues related to 3D positioning and routing of the structure was addressed to allow the specification of the various frame members, i.e. members attached to the sheet body, and or stiffening members. The system allowed non-geometric data to be assigned by the engineer, such as material type, target stiffness, etc.

The user can edit, if necessary, any of the member or panel details or positions. From a standard library of existing designs, general stiffness targets for each member can be obtained based on the overall size of the vehicle being analysed. The DART system will automatically check the member geometry and materials against the required stiffness targets and allow alterations if necessary. This is a very quick first shot analysis to ensure the vehicle being designed is realistic. At this stage, the geometry or material of the members can be altered before more costly and detailed analysis is undertaken. The DART system can be used to do 'what if' analyses by studying the effects of altering materials, removing structural members, altering the position of member's etc. This quick analysis allows the effects of change, maybe due to packaging problems to be assessed such that their relative importance to the overall stiffness targets can be assessed before a more time consuming and costly analysis is undertaken. In addition, if relevant manufacturing information is stored within the database, and the user selects a particular type of material and manufacturing method, the system will highlight any case were the rules have been violated. For example, using AML's geometric reasoning capabilities a member might return to the rule base that a radius of curvature is too small to allow the component to be manufactured using the specified method or material.

The model created at this stage can be used as a master model to provide downstream clients with exact geometry, negating the need for model replication in other systems. The model can be also used to provide more than just geometric information the non-geometric information contained within the KBE object model can also be queried to provide manufacturing or costing information, and can also be output through neutral file formats to non-integrated systems. However, the aim of the DART system is to enable rapid structure creation and a detailed FEA of the structure to be undertaken. Fig. 6 shows a system screenshot of an imported style model. Showing the build up of a frame structure using adaptive-beam-objects and automatic cast-node-joint-objects.

Fig. 7. Simplified and full model representation.

4.3. Simplified geometry for analysis

Upon receipt of a detailed CAD model of the automotive body structure in the BIW analysis area, the analyst will first seek to simplify that model. This will entail the deletion or modification of much of the detail. The analyst will then start to create the FE mesh based mainly upon past experience of how various components and features should be presented in the FE modelling package. Some items, such as the engine may be represented as a lumped mass rather than in any detail, and these may be obtained from a library of such standard parts. However, the manner in which the analyst simplifies the initial CAD geometry should be the same regardless of the size or type of vehicle being analysed as, for example, the same types of components and jointing methods are used. Thus, the types of elements used, the element size, the methods of modelling joints, etc. should be the same each time. Each time this geometry modification is undertaken the analyst repeats the same generic steps. The panels are usually are usually represented as shell elements in a FE analysis and thus, the detailed geometry needs to be simplified such that the panel is represented as a simple surface. This, in some areas, may mean that when the surface data for the panels is extracted from the detailed CAD model, gaps between adjacent surfaces may appear, or some surfaces may overlap. Before any subsequent creation of a FE mesh this surface representation may need ‘mending’. As the methods of doing this ‘mend’ are known then the KBE system can do this automatically.

The structural members for analysis are also represented as shell elements. This means that the detailed CAD model with gauge thickness again needs to be transformed into shells and the appropriate constants such as thickness applied. In some areas, the members are represented as beam elements. In this case, the detailed geometry is transformed into a beam representation and the appropriate constants, such as cross-sectional area and moments of inertia, are calculated from the solid geometry and applied to the beams. The rule sets for how the geometry is to be transformed have been created such that this is done automatically by the KBE system and the appropriate mesh automatically created.

The various panels and structural members are joined in particular ways. They may be spot welded, bonded or a mixture of both depending upon the material selected and the loads applied. Rule sets have been created for how these joints should be represented within the FE model. The particular types of joints to be used will be determined by the KBE system depending upon the surrounding material type. If a cast aluminium joint is to be used for example, then the KBE system will automatically determine the allowable mating length and adjust the connecting members automatically. This information will be used when simplifying the geometry for analysis such that the appropriate position and types of element to represent the joints is chosen and their associated constants such as stiffness are applied. Fig. 7 shows a simple structure created in DART in both its natural solid representation and then its simplified analysis representation, a simplified surface model with gauge thickness described as associated attribute thickness.

4.4. Mesh generation

Once the simplified representations of the design model suitable for the creation of a FE mesh is created it could be passed to an external system for mesh generation. However, as the AML software has a module for mesh generation, the FE mesh can be automatically generated within AML based on the rules contained within the system. Rules have been created in the DART database regarding the creation of the mesh, and hence, this is done automatically and takes only a few minutes. From the rule base the system knows which types of elements should be used. The vehicle structure requires two different types of analysis models to be created. One for stiffness analysis and one for impact modelling. Thus, two different rule sets need to be created, as the mesh required may be different for each case in terms of element types, mesh density and boundary conditions for example. Also, the output files required are different as the analyses are undertaken in different software packages.

Currently only the rule sets for the generation of the FE mesh for the stiffness analysis have been created. The output file from DART is in a format suitable for use in the ANSYS analysis software with various types of elements such as beams and shells being used. This output file contains all of the ANSYS commands required to undertake a stiffness analysis of the structure. The boundary conditions for the analysis are applied within DART from a database of

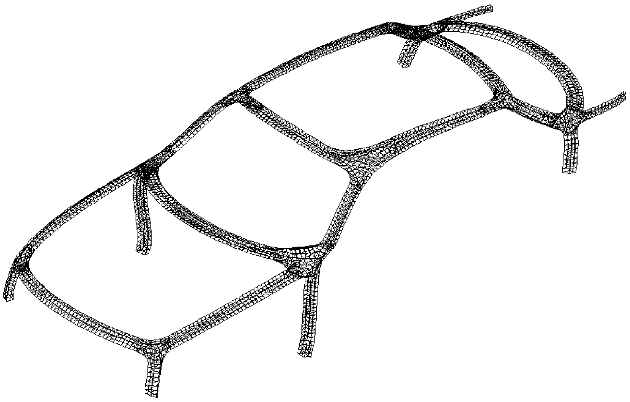

Fig. 8. Automatic quad mesh.

standard boundary conditions for different sizes and types of vehicles. Similarly, a database of material properties is available. The DART system automatically chooses the element types based on the rules such that, for example, a different shell element is used if the structure is composite to that used if the structure is steel. The user does have the ability to override the system such that solid elements may be used in place of shells for example, if they are more appropriate. As already mentioned, the element properties required by the analysis software are computed automatically. In addition, the elements are grouped in such manner to facilitate ease of manipulations.

Such automatic creation of an FE mesh based on rule sets does tend to formalise this information and allows a standardised mesh to be created time after time. This ensures that the sum methods of modelling are always used for particular items such as spot welds, such that the same types of elements are used, the same element properties are used and the geometry is simplified in the same manner. However, within such a KBE system there is always the possibility of allowing the users to override defaults such that design creativity is not stifled and other possible solutions studied. Fig. 8 shows a system screenshot of an automatic quad mesh created from design model.

4.5. Integration and graphical user interface

This task focussed on the integration of the various modules in a single framework supported by a common GUI focussing on the design automation of the vehicle frame. The application code was implemented, integrated and tested using AML. Initially the implementation focussed on the part geometry features, specifications and detailing. Once the architecture was reviewed and accepted, a custom UI was developed to enable the dynamic manipulation and modification of the part models.

5. Benefits of DART

The number of elements used in the analysis of the type of automotive structure consideration here is typically between 80,000 and 250,000 and the mesh generation can entail up to fifteen man weeks of effort upon receipt of the CAD model. Currently, due to the time and cost required to generate the analysis models, they are often used in a post-design phase to evaluate a final design that will only be modified if the results are unacceptable. This work has demonstrated that if the geometry simplification and mesh generation is achieved in a KBE system such as DART then the FE mesh can be generated in minutes. The meshing is done with respect to heuristic material and analysis solution rule bases at an object level. The FE mesh created in DART is directly associated with the model geometry and thus any alteration of the model due to packaging problems for example does not entail costly and time consuming re-work. The new mesh is automatically regenerated, reducing enormously the overall time taken for the analysis of the structure, which means that the analysis department can respond much more quickly to potential design changes imposed by other departments.

The use of DART also means that many more design options can be studied in the same time as was previously used, and thus the use of new materials to optimise the solution can be investigated. In a traditional engineering environment, more material options tends to lead to slower overall design and analysis times. Thus, these material options may not be investigated at all due to the need to do things quickly. Use of different materials in a hybrid material structure may mean that different element types are needed, e.g. composites may use a laminated shell element, and the joint types are also different. This selection of element types is done automatically in the KBE system once the material type is applied as the system has rule sets for the simplification of the geometry and the types of element to be used. Thus, the use of the DART system means that the engineers can investigate more 'what if' scenarios than would traditionally be possible due to the time constraints. These quick analyses allow the effect of alterations — may be due to packaging problems — to be assessed such that their relative importance to the overall stiffness targets can be assessed before a more time consuming FE analysis is undertaken. This should result in better, more optimised design solutions being achieved.

6. Conclusions

The use of the DART system developed here negates the need to create a new model for analysis. The detailed geometry created is automatically transformed into the form required for analysis purposes hence reducing duplication of the CAD model. As the models are all created from a unified model description duplication of data is eliminated. Thus by using the DART system the analysis department can respond much more quickly to potential design changes imposed by other departments. In addition the use of the

DART system also means that the investigation of the use of new materials to optimise the design is much easier and quicker and that manufacturing concerns can be verified from within the modelling session. The system also provides a useable model and information to other product cycle clients. Whilst the system described here is specific to an automotive structure the methodology used is generic and can be applied to any structure where the same steps in the analysis are undertaken time after time.

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