



HAL
open science

DESIGN SUPPORT TOOL FOR MATERIAL AND PROCESS COMBINATIONS DURING EARLY DESIGN

Lorraine Howard, Huw J Lewis

► **To cite this version:**

Lorraine Howard, Huw J Lewis. DESIGN SUPPORT TOOL FOR MATERIAL AND PROCESS COMBINATIONS DURING EARLY DESIGN. *International Journal of Production Research*, 2007, 44 (17), pp.3379-3390. 10.1080/00207540500529363 . hal-00512882

HAL Id: hal-00512882

<https://hal.science/hal-00512882>

Submitted on 1 Sep 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



DESIGN SUPPORT TOOL FOR MATERIAL AND PROCESS COMBINATIONS DURING EARLY DESIGN

Journal:	<i>International Journal of Production Research</i>
Manuscript ID:	TPRS-2005-IJPR-0034.R1
Manuscript Type:	State-of-the-Art Review
Date Submitted by the Author:	07-Oct-2005
Complete List of Authors:	Howard, Lorraine; C.I.T, Mechanical Engineering Lewis, Huw J; University of Limerick, Department of Mfg and Ops Engineering
Keywords:	ADVANCED MANUFACTURING TECHNOLOGY, CAD/CAM, DESIGN, EXPERT SYSTEMS
Keywords (user):	



1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Name: Lorraine Howard

Address: Dept. of Mechanical Engineering, Cork Institute of Technology,
Bishopstown, Cork. Ireland.

Affiliation: Dr. Huw Lewis, Department of Manufacturing & Operations
Engineering, University of Limerick. Ireland.

Telephone no.: 021-4326742

Fax no.: 021-4326627

Email: lhoward@cit.ie

Word count: 4752

Style Definition: Figure: Line
spacing: single

Style Definition: picture: Line
spacing: single

Deleted: 3683

Top Peer Review Only

SUPPORT TOOL FOR MATERIAL AND PROCESS COMBINATION

Deleted: DESIGN

Deleted: OPTIMISATION

1. L. Howard, Department of Mechanical & Manufacturing Engineering,

Cork Institute of Technology, Cork.

2. Dr. H. Lewis, Department of Manufacturing & Operations Engineering,

University of Limerick, Limerick.

ABSTRACT

The aim of this research is to develop an Expert System (ES) that is linked into a 3D design package, which will provide comparison data for various material and manufacturing process combinations to produce a design. The early design stage is the optimum time to ensure that the material and manufacturing process chosen will realise a design's requirements.

This paper focuses on the steps within the process to create the Expert System and provides an example of its use. The CAD package chosen is AutoCAD 2004. A recognition module has been developed to recognise a 3D model and to segregate the model into that of the quadratic and polyhedron primitives within a database. A generic material and manufacturing database has been designed. This has established a basic platform from which the different material and manufacturing processes can be compared. As each manufacturing process has process specific rules, it is necessary to examine the 3D model for the suitability of the processing method chosen within the ES.

1
2
3 This ES aims to increase the knowledge available to the designer to aid in the
4 decision-making process, through the comparison reports generated and the web link
5 and specific documentation facility within the software package.
6
7
8
9

10
11 **KEYWORDS: CAD, EXPERT SYSTEM, DESIGN**
12
13
14

Deleted: ,VBA

15 **1. INTRODUCTION**

16 Initial design is a vital stage of a successful product's development. It is at this
17 stage that the qualitative and vague marketing definitions of a product are quantified,
18 and as the complexity of the product is increased the more alternatives there are that
19 will match the required characteristics of the product. To find the "Best" or "Optimal"
20 design is an iterative process. Previously, the attention had always been focused on the
21 manufacturing process to reduce the costs. This only represented about 30% of the
22 products cost area. It has been estimated that design costs only 5% but that as much as
23 70% of the cost of a manufactured part is decided at this stage [1]. Design is an area
24 where a good return on time investment can be realized through good design practice.
25 There are many Concurrent engineering techniques, which prove invaluable to good
26 design practice, utilizing QFD, the Design for suite (DFA, DFS, etc), Axiomatic design
27 and Value engineering, to mention but a few. Yet at the end of all of these techniques
28 one problem remains for the designers, the optimal material and manufacturing process
29 combination.
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44

45 With a design in hand the designer needs to know what material should be chosen
46 and how can it be processed to suit their specific needs, simultaneous to the 3D design.
47
48 There are software packages that consider single specific domains for processing 3D
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 models, such as machining [2-4], casting [5], injection moulding [6], forming [7], etc,
4 and these are viable tools when a process route has been established for a design and
5 finite costing for tooling and fixturing is required, but these do not consider material.
6
7 There are also material knowledge systems [8,9,10] available that consider material and
8 manufacturing compatibility, which is invaluable at the final stages of design with the
9 in-depth knowledge of materials provided. Yet at the earlier stages in design these
10 systems do not provide comparison charts to depict the associative costs and aesthetics
11 expected for the various material and manufacturing combinations. Nor do they provide
12 details comparing the suitability of different processing methods for a 3D design. This
13 ES aims to fulfill this niche.

14
15 The materials available for selection are extensive, as are the methods of
16 manufacture to produce a design. Not all materials lend themselves to the same method
17 of manufacture and each manufacturing method has its specific design rules. It is within
18 this discipline that this research focuses. The ES developed provides a designer with
19 the data required to screen and select a suite of suitable materials for the design. Each
20 material can be investigated to compare the different manufacturing processes suitable.
21 Manufacturing difficulties within the design are then informed to the designer through
22 the ES. On completion of the ES the designer is presented with reports detailing the
23 suitability of the design for each manufacturing process considered for the material,
24 along with a breakdown of the range of costs, economic order quantity (EOQ), and
25 aesthetics. With these a design team can compare the attributes of the material and
26 manufacturing process combinations and select the combination that best suits their
27 needs for the design. This information offered simultaneous to 3D design aims to bridge

Deleted: With a design in hand the designer needs to know what material should be chosen and how can it be processed to suit their specific needs.

Deleted: kingdom of

Deleted: s

Deleted: is

Deleted: vast,

Deleted: optimal

Deleted: for

the gap between CAD and Computer Aided Process Planning (CAPP) to aid product development and improvement.

The methods used to develop the system will be database design, and expert system development, along with concurrent engineering methodology.

2. THE ES AND CAD SYSTEM

The CAD package chosen to establish the ES within was AutoCAD 2004. It has solid model capabilities and also lends itself towards customisation. The ability of the system user to continue working within a familiar environment greatly reduces their learning curve when dealing with new software. The AutoLISP language was chosen to extract the 3D model data initially and Visual Basic Applications (VBA) provides the user-friendly interface and the programming capabilities to create the ES and communicate with the different software used.

2.1 The 3D model capabilities

The 3D model is constructed using Boolean operations on basic primitives or swept shapes. Utilising this method ensures the 3D model created will be a valid solid.

The 3D model does not require tapers or radii as these only increase computations and these process dependant features will be advised for the process chosen at a later stage in the ES.

The 3D model volume and bounding box detail (the minimum and maximum coordinates) were extracted directly to a text (MPR) file. The information pertaining to the 3D model structure was retrieved from the AutoCAD database in the form of Boundary Representation (B-rep) data. This defines the boundary information of a solid

Deleted: Within AutoCAD t

Deleted: by

Deleted: the chosen

Deleted: ¶

Deleted: that is

Deleted: is

in terms of face, edge and vertices, together with the information on how they are connected. The B-Rep data extracted is in a SAT file format.

Deleted: This is achieved through AutoLISP using the ASCIOUT command, which produces a SAT file of data strings [2-3].

Deleted: ¶

A SAT file is a 3D format created by Spatial Technologies and is characterised as a 3D boundary representation geometric model, which is supported by many solid-modelling systems. The SAT file is the basic file required from AutoCAD for conversion to the STEP format. There has been some standardisation within the CAD/CAM industry to facilitate the integration of products, through the use of STEPS [11]. This has established a common platform from which software packages can compare and assign to their particular tasks. STEP conversion is a third party software [12] and is also still in its infancy, so it was not feasible to incorporate it into this stand alone ES. Thus the need to use the SAT file. The main drawback of the SAT file was the interpretation of data for the 3D model. The geometric data associated with the B-Rep model was obvious, but the topology of the model was not clearly evident within the SAT file and this would require the development of algorithms to determine the connectivity of the edges and planes within the 3D model.

Deleted: 4

Deleted: As

Deleted: it could not be

Deleted: d

Deleted: and

Deleted: was utilised instead

Deleted: was retrieved,

Algorithms were developed to extract the geometric data from the text file into lists denoting the entities present within the B-Rep model. Mathematical models were then developed to examine the relationships between the entities to determine existence of the basic polyhedron and quadratic primitives. These models provided the logic for the algorithms used to verify the existence of quadratic and polyhedron primitives occurring within the model. Papers detailing this procedure have been written [13,14].

An ES database was created to store information on the 3D CAD model data extracted. The information transferred to the database was of the following format:

1. Quadratic primitives : A table which denotes circular data regarding :

Formatted: Numbered + Level: 1 + Numbering Style: 1, 2, 3, ... + Start at: 1 + Alignment: Left + Aligned at: 28.35 pt + Tab after: 46.35 pt + Indent at: 46.35 pt

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

- a. The acting axis of a cylindrical feature.
- b. The central co-ordinates of this axis.
- c. Whether it's a full or partial radius.
- d. The number of cylindrical features on the same axis.
- e. The minimum and maximum depth of the feature.
- f. The minimum radius (if a taper exists) and the maximum radius.
- g. Blind or through feature.
- h. External boss or not.

Formatted: Numbered + Level: 2 + Numbering Style: a, b, c, ... + Start at: 1 + Alignment: Left + Aligned at: 64.35 pt + Tab after: 82.35 pt + Indent at: 82.35 pt

Formatted: Bullets and Numbering

2. Polyhedron primitives: Consisting of four tables

- a. Containing the plane detail and the associated edge quantity.
- b. Containing Edge detail and a link to plane identity (above).
- c. Containing Edge detail with a unique edge identity.
- d. Containing the Point detail.

Formatted: Numbered + Level: 2 + Numbering Style: a, b, c, ... + Start at: 1 + Alignment: Left + Aligned at: 64.35 pt + Tab after: 82.35 pt + Indent at: 82.35 pt

Deleted:

Formatted: Font: Not Bold, Not Italic

Formatted: Bullets and Numbering

Formatted: Font: Not Bold, Not Italic

3. Mass properties : A table containing the volume of the 3D model, along with the bounding box coordinates of the 3D model.

Formatted: Indent: Left: 28.35 pt, Hanging: 28.35 pt

The designer initiates the ES (Fig 1), by clicking on the design icon, prompting the designer to select the 3D model. Once this has been done the data concerning the model is extracted to the pre-designed database for the 3D Model. Further computation of the 3D data occurs later in the ES. At this stage in the process the designer is presented with selecting the property profile required by the 3D model (Fig 1). These are the material and manufacturing modules of the ES.

Deleted: The geometric data associated with the model was transferred to the database. As the topological (i.e., adjacency relations) information is not readily retrievable from the SAT file through AutoLISP, the connectivity was determined at a later stage in the ES through VBA in order to fully define the polyhedron and quadratic primitives that exist within the 3D model.¶ Within the AutoCAD environment t

Deleted: can

Deleted: .

Deleted: This

Deleted: s

Deleted: user

Deleted: through AutoLISP and saved

Deleted: a

Deleted: Microsoft Access

Deleted: through VBA

Deleted: as B-rep data

Deleted: ,

Deleted: which are programmed through VBA.

3. MATERIAL AND MANUFACTURING PROCESS KNOWLEDGE

The nature of data needed in the early stages of design differs greatly in its level of precision and breadth from that needed at the embodiment stage. At the early stage the designer requires approximate property values and the widest possible range of materials [15]. For example, for materials such as mild steel or aluminium, ranges are given to cover the properties for the classes within this material. Similarly generic data has been used for the manufacturing processes. A database with both the material and manufacturing tables has been created for the ES, utilising several sources of valid information [8-16-20].

Within this database the basic properties for each material were grouped into tables detailing mechanical, thermal, electrical and environmental attributes. The basic properties of the manufacturing process were grouped in tables for process attributes, size and dimensional accuracy, economics, model capabilities and material suitability.

When selecting a material for a design the following factors need to be decided on by the design team [15]:

- What properties are required and whether the required properties will be maintained during the service life of the product.
- Whether it will cause environmental problems.
- Whether the material can be processed to the required shape and dimensional accuracy.
- Whether the material can be economically used to produce the product.

The first two factors are addressed within the material selection module and the latter two within the manufacturing process module within the ES.

Deleted: only

Deleted: in Access

Deleted: 6

Deleted: 1

Deleted: the

Deleted: for

3.1 Material selection module

A designer decides what performance is needed by a design, through establishing a property profile. This is defined by the function, objective and constraints required by the design. A design may have one or more functions. Its function may be to transmit heat, to support a load or to contain pressure for example. As well as this the design must fulfil an objective. It may be required to be as lightweight and / or as cheap as possible. All designs have constraints, which could be the environment, temperature range or the load it must withstand. All these criteria create a property profile for the design. By applying these property limits the wide range of materials is narrowed through screening. This may appear over simplistic, but the material selection process must be broken down into clear concise steps to facilitate programming.

The ES initially requires the designer to input the required property profile through the mechanical and/or thermal/electrical profile options (Fig1). The property profile can be input as a minimum or maximum value required. Note that only values larger than zero are considered by the ES. The designer is then required to input the level of environmental protection required by the design (Fig 2). Utilising all these properties, the Microsoft Access query facility screens the database for a suitable subset of materials, presented as a drop down list to the designer. Information is the key and the designer is able to view the properties of each material within this subset and print off the data if required. An example for the information available on the mechanical data is shown in Figure 3 for the aluminium alloy family of materials, suitable to the property profile input.

Deleted: An

Deleted: example is shown here for a 3D model where the mechanical property inputs are for strength and density (Fig 2)

Deleted: The property profile input by the designer is saved to the database.

Deleted:

Deleted:

Deleted: through

Deleted: is screened

Deleted: .

Deleted: This subset of suitable materials is

Deleted: environmental

1
2
3 The designer can review as many materials as required here, but a single material
4 must be selected to process further. The other materials within the subset can be
5 returned to at a later stage to process.
6
7

8
9 Within this part of the ES the designer also has the option to link to the Internet
10 for information on materials and their properties, through pre-established web sites.
11 Here the designer can view material selection charts if required. There is also the
12 opportunity, if the ES is being used for a quick review, to choose a material directly
13 from the database to process.
14
15

Deleted: Once the material is chosen
this is downloaded to the database

16
17 Within the material selection of the ES the option also exists to examine utilising
18 heat treatment to provide the required mechanical properties and/or to examine applying
19 a surface coating to provide the required protection. These are processes, but are
20 important to consider here as they may affect material choice. Once the material choice
21 is finalised the ES proceeds to the manufacturing selection module.
22
23
24
25
26
27

Deleted: and

Deleted: in

3.2 Manufacturing process selection module

28
29
30
31 The processes that are suitable to the material chosen are screened. The designer
32 is given these processes in a drop down list and can choose to review them individually.
33 Like the material module the attributes associated with the process are available to the
34 designer to view and to print if required. The designer must then choose a process to
35 examine within the ES. It is at this stage that the further computation of the 3D model
36 data occurs.
37
38
39
40
41
42

Deleted: through the Microsoft Access
query facility

3.3 Generating the 3D model specifics

43
44
45
46 It is within this section that the real investigation of what the 3D model contains
47 takes place. The area of feature recognition is vast and this thesis is only touching on the
48
49
50
51

Deleted: through VBA programming

tip of the iceberg with basic recognition. The reasoning being that this thesis is about an area other than feature recognition alone, but as it encompasses it, it is necessary to achieve some level to proceed.

When integrating CAD with manufacturing applications the difficulty lies in how to interpret the low level CAD information automatically into a useful format for selecting an appropriate method of manufacture. Here automatic feature recognition has been used, where the data structure of the geometric model is examined to discover and extract its features automatically. The mechanism used in the ES to determine automatic feature recognition is a combination of rule-based method, mathematical modelling and graph based methods. This was achieved in Section 2.1, through extracting the data pertaining to the polyhedron and quadratic primitives into the ES 3D database. In order to determine what further feature recognition is required, it was necessary to establish the process parameters required to determine the overall model suitability. The parameters selected were the suitability of

1. The mass of the model,
2. Its overall maximum dimension,
3. The material thickness, and
4. The hole size range allowed

by the process. The parameters for the mass, the maximum dimension and the hole size were readily available in the ES 3D database (Section 2.1). The material thickness required further recognition algorithms to be developed.

In order to establish this parameter, the topology of the model was determined. Firstly the edge connectivity was determined for each plane in the model. Each plane within the 3D model can be bounded by straight edges, angled edges and/or curves.

Formatted: Bullets and Numbering

Formatted: Indent: First line: 0 pt

Deleted: ¶
Firstly

Deleted: is

1
2
3 Where each edge or curve finishes and another one begins, is connected by a point. This
4 connectivity eventually reaches back where it started from, forming a continuous loop
5 around the shape. Search algorithms were developed using IF-THEN logic to establish
6 this connectivity, where each plane has its edges & points identified with a unique Loop
7 identity number for each loop on a plane. If more than one loop was found on a plane
8 the loop with the largest internal area was denoted as an external loop and the other as
9 an internal loop.

10
11 With these loops identified the next section of programming established the
12 connectivity of the planes within the model. It did so by starting with a plane having an
13 internal loop. Using this loops identity and its edge connectivity, the planes connected
14 to these edges were determined through basic algorithms and the database query
15 facilities. This data was then compared to the other loop identities and edge
16 connectivity's. This search process continues until all the internal and external loops
17 have been accounted for. The resulting table contains data regarding the top and base
18 plane for each non round feature, a link to the loop identities and the overall depth of the
19 feature. With these basic building blocks of the model established, the material
20 thickness can now be determined.

21
22 Each internal loop was reviewed to calculate the material thickness. Using each
23 internal loop identity and the building block it belonged to, its relationship with the
24 external loop on the same plane was examined. If the internal loop building block depth
25 was in the same direction as that of the external loops building block depth then the
26 internal loop was an internal feature and the material thickness for that plane was
27 established. If the opposite occurs then the material section has narrowed but, because
28 it was travelling in the opposite direction then it is part of the outer model. Its material

Deleted: At the end of this module

Deleted: With the loops established it is now possible to set up VBA subroutines to determine specific details about the 3D model which is needed for the following sections on the determination of process suitability and specifics. ¶
Firstly, utilising the loops on a plane enabled the calculation of the distances between the outside of a circular feature (hole or boss) touching that plane and an outer edge or inner feature. The minimum distance calculated from each loop on a plane is downloaded to the database for each face of a circular feature. ¶
Secondly,

Deleted: seeks to

thickness will be picked up by the next internal loop searched. If there are no internal sections then the overall thickness of the model along the Z axis was considered as the material thickness.

Another process rule that occurs regularly is the nearness of a feature to an edge. Utilising the knowledge developed about the loops on each plane enabled the calculation of the distances between the outside of a circular feature (hole or boss) touching that plane and an outer edge or inner feature. The minimum distance calculated from each loop on a plane was downloaded to the database for each face of a circular feature.

The database now had enough information about the 3D model to proceed in examining the processes suitability and model specifics.

3.4 The 3D model process suitability

The overall suitability of this process for creating the 3D model is reviewed through comparison of the information generated through the recognition algorithms and that from the relevant tables within the database. The suitability is then informed to the designer through the ES (Fig 4).

Even if the process is unsuitable for any of the above the designer can still proceed to examine the process and generate the reports. Remember design is an iterative process and the economics report may encourage redesign of the model at this early stage. Also as the database is generic it contains ranges of data, which can over exaggerate the figures, for example the allowable mass, whereas when a specific material type is chosen this may be found to be suitable.

So far only the basic suitability of the process has been considered. Every process has manufacturing rules, which need to be adhered to. These are rules like hole depth to

Deleted: non-round internal features within the 3D model. It looks for basic slots or hollows within the 3D model, as well as the outside basic shape. It does so by starting with an internal loop on a plane and determining its connectivity. When all the internal loops have been accounted for, the external loops without prior connectivity are accounted for. This is necessary to account for internal features and also to determine the material thicknesses of the model.

Deleted: has

Deleted: ,

Deleted: through

Deleted: ¶
<#>The suitability of the mass of the model, ¶
<#>Its overall maximum dimension, ¶
<#>The material thickness and ¶
<#>The hole size range allowed by the process. ¶
This

Deleted: is retrieved from

Deleted: and compared

1
2
3 diameter ratios, suitability of the different axes for processing features, minimum radii,
4 and so on. This process information set up as a table within the ES material database.
5
6

7 These process rules are advised now rather than at a later stage in design, when all the
8 detailed drawings have been finalised and the model is sent to the manufacturer for
9 exact costing. The design at this stage is still in its infancy and as accurate costing will
10 eventually need to be sought, it would be beneficial not to have to redesign at a later
11 stage. So these rules are considered now.
12
13
14
15
16

17 **3.5 The 3D model processing specifics**

18
19 The option to review the specifics of the 3D model with respect to the chosen
20 process is given to the designer (Fig 4). The specifics reviewed are those, which apply
21 to the bosses, the round and non-round holes within the model. For example, for each
22 hole within the model, the suitability of its axis for processing, the hole type – through
23 or blind, the diameter to depth ratio and its distance from each edge on a plane is
24 checked through comparison algorithms within the ES database. In this example, the
25 22mm deep through hole, 10 mm in diameter (Fig 1) is reviewed. For the Die press and
26 sintering process selected, the depth to diameter ratio for a through hole is 4:1, the edge
27 distance of the hole from its nearest edge is greater than the minimum material thickness
28 of 1.5mm allowable between holes and edges. This 3D model is shown to be within
29 these specifications. Yet the axis along which the hole is to be processed is not
30 allowable by Die press and sintering. The designer is informed here that a secondary
31 operation is required (Fig 5). Similarly, the boss and the internal slot (Fig 6) show up as
32 requiring secondary operations to create. Therefore the designer would see that this is
33 not a suitable process to proceed with for the design.
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 There are many other specifics about this manufacturing process and the designer
4 can review these process specific rules here. A document detailing other rules such as
5 material thickness changes, minimum radii required, draft angles, rib placement, etc are
6 supplied here for the designer. Knowledge of the process specifics here can make all the
7 difference between choosing the right and wrong process and incurring costs down the
8 line trying to rectify this.
9

10
11 Following this process investigation, the designer can select the process for
12 comparison (or not) and return to review the process specifics of the other
13 manufacturing processes suited to the chosen material. This information is then
14 compiled into reports within the database.
15

26 4. COMPARISON REPORTS

27 When content with the processes selected for comparison for a specific material
28 the designer can print off two main reports. The first of these is that of the basic
29 suitability of the process (advised in Fig 4) along with the material chosen and its cost
30 per Kilogram. The second report (Fig 7), details the economics of each process along
31 with their aesthetic ability. This information provides a good basis for comparison
32 between the different processes for a designer.
33

34
35 The cost index is a major economic comparison indicator between the processes.
36 It represents the total cost range per unit to the company. This is based on the material,
37 dedicated tooling and gross overhead costs. The material cost uses the 3D model
38 volume, material density range, material cost and material utilisation from the database
39 for each process. The tooling cost and gross overhead cost are based solely on process
40 economics.
41
42
43
44
45
46
47
48
49
50

Deleted: 6

1
2
3 The aesthetic ability of the process looks at the quality, roughness and tolerances
4 achievable through each process. These would be of vital importance. Secondary
5 operations may be required to achieve the aesthetics of the design. These are not
6 considered by the ES but, by highlighting the aesthetic ability the designer is aware of
7 the capabilities of each process.
8
9

10
11
12 In this example, the 'Manufacturing process economic data' report (Fig 6) has
13 shown the comparison data for two near net shape processes for the aluminium alloy 3D
14 model. With these the designer can see at a glance that if the economic order quantity
15 (EOQ) required was greater than four thousand then the high pressure die casting would
16 be the process to choose. If the EOQ was less than a thousand then the ceramic mould
17 casting would be the chosen process. In this instance the mass of the 3D model was the
18 main restricting variable for the number of suitable processes, coupled by the process
19 specifics. The former could be rectified by a material change. Following the completion
20 of the above reports the designer can review another material from the original screened
21 set of materials to investigate the processing of, if so required. This is in keeping with
22 the iterative nature of design as there is no one single solution and knowledge is the key
23 to ensuring the best design is chosen.
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38

Deleted: The designer has an option after printing

Deleted: to return to

Deleted: alternate

Deleted: for

39 5. CONCLUSION

40
41 During the design, the material and manufacturing process combinations will be
42 chosen from those with which the product design team is most comfortable [1]. As a
43 result, the opportunity for major manufacturing improvements may be lost through the
44 limited selection of manufacturing processes and associated materials in the early stage
45 of product design. This ES would provide a useful tool when designing in an era where
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 concurrent engineering is paramount. It harnesses knowledge in the material and
4 manufacturing area, which is readily available at the designer's fingertips when
5 required. This it achieves through its internal database and links to predetermined web
6 sites and documents.
7
8
9

10 Information can be retrieved and printed readily throughout the ES. The final
11 reports generated would aid the designer in the economic and aesthetic comparison of
12 various material and manufacturing process combinations. With these an optimum suite
13 of material and manufacturing process combinations could be analysed. At this stage in
14 the development of the ES, it does not consider material removal or the tooling costs
15 associated with this process. The ES provides advice on the tolerances that would be
16 produced by the near net shape processes selected and the associated costs to achieve
17 this.

Deleted: and a design option finalised

18
19
20
21
22
23
24
25
26
27 The aim here was to create an ES that would be simple to use and could supply
28 knowledge in the various areas required for product design. At the early stages of design
29 this ES could be utilised easily by a design team. The ES works within a familiar
30 environment and provides the designer with a user-friendly graphical user interface
31 (GUI) through simple forms, input boxes, option and command buttons.
32
33
34
35
36

37 This paper has detailed the basic format of the ES created to aid the designer in
38 selecting material and manufacturing process combinations at design. It has shown how
39 the reports and information generated through the ES can aid the designers with their
40 optimal design combination in an aim to reduce the errors that can appear in designs
41 once they enter the production process.
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Deleted: optimising

6. REFERENCES

1. Ullman, D.G., *The Mechanical Design Process*, 2nd Ed, Mc Graw-Hill, 1997.
2. *Licom Internet site. Available on line at : www.licom.com*
3. *AUTO-CODE Mechanical internet site. Available on line at : www.autocode.com*
4. *Intercim NC solutions centre. Available on line at : www.austinnc.com*
5. *CASTech software . Available on line at : www.castech.fi*
6. *Moldflow internet site. Available on line at : www.moldflow.com*
7. *FemForm software internet site. Available on line at : www.femengineering.com*
8. Cebon, D., Ashby, M.F., Lee-Shothaman, L., Cambridge Engineering Selector Version 4 (CES4), 2002, Granta Design Ltd.
9. *Material data . Available on line at : www.matdata.net*
10. *ASM handbook . Available on line at : www.asminternational.org*
11. Han, J.H., Kang, M. and Choi, H., STEP-based feature recognition for manufacturing cost optimisation, *Journal of Computer-Aided Design*, 2001, **33**(9), 671-686.
12. *STEP conversion from StepTools. Available on line at : www.steptools.com*
13. Howard, L., Lewis, H., *A manufacturing cost analysis tool for 3D design*, 12th International conference Flexible Automation & Intelligent Manufacturing Dresden, 15-17th July, 2002 pp. 1174-1184.

Formatted: Bullets and Numbering

- 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
14. Howard, L., Lewis, H., *3D feature recognition – an integral part of modern design*, 20th International Manufacturing Conference CIT Cork, 3-5th Sept, 2003 pp. 77-83.
15. Ashby, M.F., *Materials selection in mechanical design*, second edition, 2003, pub Butterworth-Heinemann.
16. Philip, M., Bolton, B., *Technology of Engineering Materials*, 2002, pub Butterworth-Heinemann.
17. Swift, K.G., Booker, J.D., *Process selection from design to manufacture*, 1997, pub Arnold.
18. Cubberly, W.H., Bakerjian, R. (Editors), *Tool and Manufacturing Engineers Handbook (TMEH)*, Desk Edition, 1989, pub SME.
19. Beitz, W., Küttner, K.-H. (Editors), *Dubbel Handbook of Mechanical Engineering*, 1994, pub Springer-Verlag London limited.
20. Boothroyd, G., Dewhurst, P., Knight, W., *Product Design for Manufacture and Assembly*, Marcel Dekker, Inc., 1994.

Deleted: <#>Han, J.H., Kang, M. and Choi, H., STEP-based feature recognition for manufacturing cost optimisation, *Journal of Computer-Aided Design*, 2001, **33**(9), 671-686. ¶

Deleted: <#>Cebon, D., Ashby, M.F., Lee-Shothaman, L., Cambridge Engineering Selector Version 4 (CES4), 2002, Granta Design Ltd. ¶

Formatted: Indent: Left: 28.35 pt

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

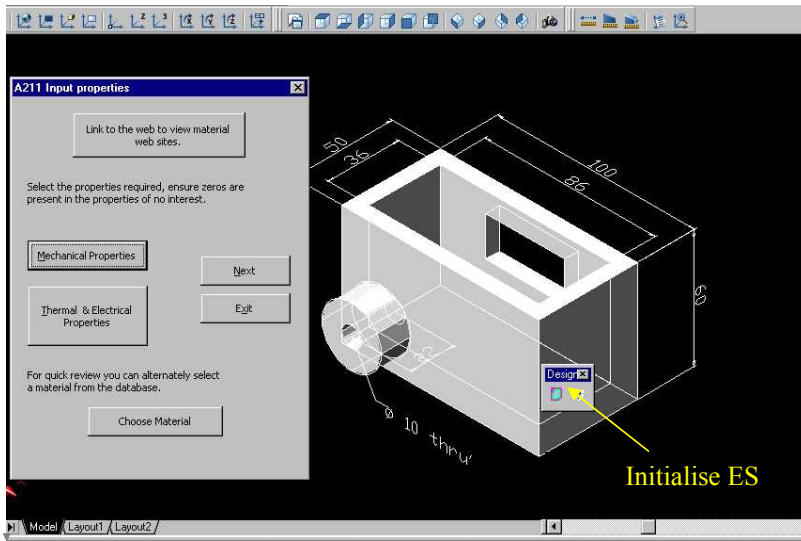


Fig 1. Initialise ES & select required property profile

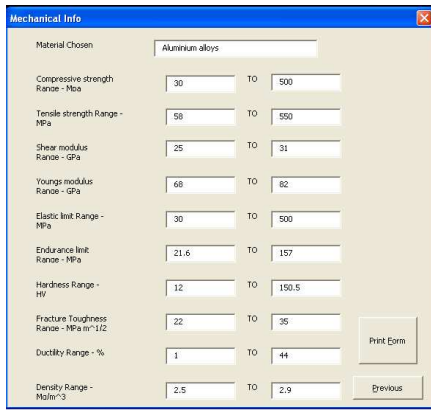


Fig 3. Mechanical properties



Fig 2. Environmental properties

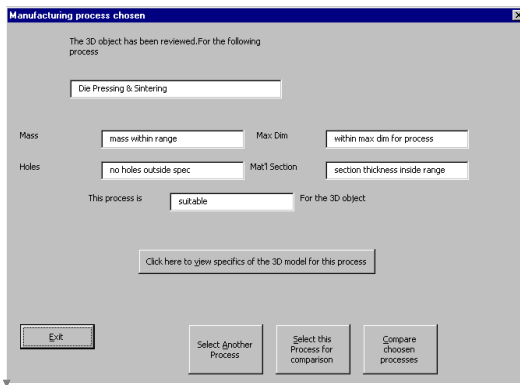


Fig 4. Process suitability

Formatted: Font: 8 pt

Formatted: picture

Deleted: -----Page Break-----

Deleted: <sp>

Formatted: Font: 12 pt, English (Ireland), Check spelling and grammar

Formatted: picture

Property	Minimum Value required	Maximum required
Compressive Strength MPa	0	0
Tensile Strength MPa	300	0
Shear Modulus GPa	0	0
Youngs Modulus GPa	0	0
Elastic Limit MPa	0	0
Endurance Limit MPa	0	0
Hardness Vickers HV	0	0
Fracture Toughness MPa m ^{1/2}	0	0
Ductility % elongation	0	0
Density Mg / m ³	0	8

Deleted:

Formatted: Indent: Left: 22.5 pt, First line: 7.5 pt

Deleted: 2

Deleted: . . .

Deleted: 3

Deleted: ¶

Formatted: picture

Deleted: ¶

Formatted: Font: 10 pt, Bold

Deleted:

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Fig 5. Process specifics for hole

Fig 6. Process specifics for nonround hole

Formatted: Tabs: 213.75 pt, Left + Not at 296.25 pt

Formatted: Tabs: 217.5 pt, Left + Not at 296.25 pt

Formatted: picture

Manufacturing Process Economic Data

Process Name *Ceramic Mould Casting*

Cost Index		Tooling Cost range		Capital range		Roughness range (micro m)		Quality range	
€18.34	€95.19	€139	€1,394	€697	€6,970	1.6	3.2		6
MaxEOQ		Lead Time (wks)		Material Utilisation		Production Rate (Kg/Hr)		Tolerance range (mm)	
50	1,000	1	3	0.6	0.75	3	30	0.38	0.8

Process Name *High Pressure Die Casting*

Cost Index		Tooling Cost range		Capital range		Roughness range (micro m)		Quality range	
€10.70	€97.77	€6,273	€90,610	€139,400	€597,000	0.8	1.6	1	6
MaxEOQ		Lead Time (wks)		Material Utilisation		Production Rate (Kg/Hr)		Tolerance range (mm)	
4,000	800,000	4	8	0.75	0.85	16	480	0.15	0.5

Fig 7. Economic and aesthetics report

Formatted: Indent: Left: 30 pt

Deleted: 6

View Only