	ECOMP *COOP-CT-2003-508149* ***Agent-Based Engineering in a cost-estimation model for composites***

Publishable Final Report

- General evolution and overview of Ecomp project -

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CRIC
CENTRE DE RECERCA I INVESTIGACIÓ DE CATALUNYA

Sixth Framework Programme

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1. Project Summarization

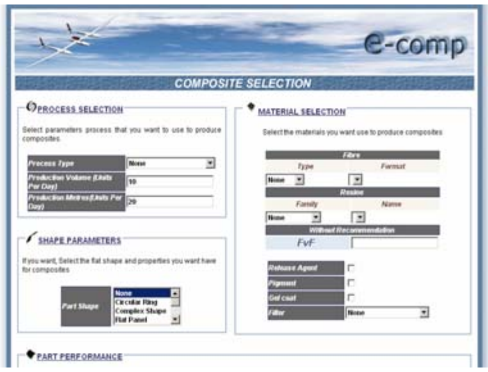
The market for composites is growing steadily, including commodity type applications in the automotive, civil infrastructure, and other emerging markets. A major obstacle to achieving the full potential of composite structures in many applications is cost-effective manufacturing.

The **scientific challenge** of this project lies in the application of web based and agent-oriented software engineering to cover the real need of computing time and cost estimates in the expanding market of composite designs, as well as assisting designers in evaluating cost reduction strategies based on advanced computing techniques, which can be easily and readily accessed and used by SME's in their efforts to remain at the forefront of technological developments and to be well-positioned to compete on the global scene.

The **technical objectives** of this project lie in the development, verification and validation of a web-based and agent-based infrastructure that will assist composite manufacturers, equipment and tooling manufacturers, product designers and process engineers in developing new and better products, optimising processes, choosing equipment configurations and materials from a wide range of suppliers by providing them with a tool to assist them in evaluating cost reduction strategies so that they can confidently make decisions early on during the design phase.

All the technical objectives have been achieved successfully except the WebCrawler Agent development, where only a study has been possible, due to the lack in the wide implementation of web services thorough the composites community nowadays.

Different **methodologies** have been used for the project development. Time scheduling has been used as the base for the project development. The different data and calculus procedures have been developed initially with tailored templates which permitted the validation on behalf the different expert partners of the project. Finally, the templates have been traduced in program code into the system. All the work has been summarized in form of deliverables and regular meetings have been carried out during the project for ideas exchange and the study of the state of the project.



The technologies involved have been: Java as main language, JSP for active pages, MySQL for data bases, and Jade for agent oriented programming. After the mid point revision, the object oriented approach has been used for materials, properties and process selection, meanwhile the agent oriented approach has been adopted for the cost model modules.

The **contribution to the state of the art** is the creation of a system for cost modelization and material, process and properties estimation in the early stage of the composite selection. Ecomp is the first tool for the selection of these different issues in an early stage in a wide aspect for different types of processes and materials.

The **final results of the ECOMP project** can be seen at the http://www.ecomposites.eu[1] internet address. The web-based system[2] require information on the final product requirements,

[1] Valid address in 1 December 2006

production and cost limitations and guides the user along the process of materials selection, manufacturing parameters, properties and others. It estimates the cost of selected alternative roots and inform of other non-economic issues to aid the user in making knowledgeable decisions.

Two main parts can be seen divided in the whole system:

- *Composites expert knowledge acquisition*: The Composites technology knowledge is gathered mainly from industrial partners and RTD performers. The research seeks to capture the human solving knowledge used in composites, organize this knowledge and other numerical computing required for the control and design activities, and provides the computer software frameworks to strategically exercise this knowledge.
- *Web-Based expert system*: The system apply knowledge and reasoning features to proceed to the appropriated composite material selection, properties and costs. Uses the expert data obtained in the previous point and proceed to the proper calculus for helping the composite designer from the very early stage design in an easy way of use and user customization.

The final developed is capable to performing different activities for the composites professionals in the early stages of composites election. One of its main strength is that depending on the inputs to the system, different outputs are achieved. The different possibilities are illustrated in the point "3 - System Description".

[2] The Ecomp system provides guidance in its own use by means of downloadable documents.

2. Contractors involved

- IVA LEYING, S.A / Spain: IVA LEYING, S.A. has focused on such sectors as industrial engineering, civil engineering, architecture and environment and thus directs its investigation to these areas. Design with composite structures has been of crucial interest for them over the past few years.

- NetComposites Ltd. / UK: NETCOMPOSITES, based in the UK, administrates a composites web site named "netcomposites.com". Their site offers useful information to the entire composites community and has a unique distribution of composite books and articles.

- IZR SOLUTIONS Ltd. / UK: IZR SOLUTIONS Ltd. is a leading provider of ASP, e-commerce and Internet Solutions. IzR specialises in IPVPN implementation and support, VoIP consultancy and solutions and a range of Internet connection services

- MOLDER-DISNOVA, S.L / Spain: MOLDER-DISNOVA, S.L. was founded in 1994 and since then has been dedicated to the production of reinforced moulded parts, especially glass fibre reinforced polyester, using Simultaneous Projection and R.T.M technologies.

- Aristeides Stathopoulos & Co / Greece: Stathopoulos is located in the Peloponnese, Greece. The company specialises in the manufacture of seasonal decorations made out of polymer materials. Their main products are outdoor relief decorations, with sizes varying from relatively small representations up to real size or even huge dimensions.

- GLAS-CRAFT Ltd. / UK: GLAS-CRAFT is a private UK company specialising in the field of machinery, moulds and other equipment employed in the composites industry. The company offers a comprehensive range of meter mix machines, moulds, moulding ancillaries and dispensing equipment.

- JAMES QUINN ASSOCIATES, LTD / UK: James Quinn Associates has been in practice for the past 12 years as consulting engineers specialising in composite materials and products. Their primary activity is the engineering design of composite structures but they also run training courses and they also publish a design manual and a CD ROM of suppliers of composite materials.

- Centre de Recerca i Investigacions de Catalunya, S.A. (CRIC) / Spain: CRIC is a multidisciplinary research centre based in Spain, which aims at assisting small and medium enterprises to become more competitive through technological innovation, respecting the environment and improving products, processes or services that help better the quality of life. CRIC has been involved in several EU funded projects.

- AIMPLAS (Instituto Tecnológico del Plástico) / Spain: AIMPLAS, Technological Institute of Plastics located in Valencia, is a private, non-profit Association with more than 410 associated companies (the majority of them SME's). AIMPLAS has offered its services to the Plastic industry sector since 1990 and, nowadays, has a permanent staff of 50 persons; 20 researchers, 22 qualified technicians and 8 staff support personnel. AIMPLAS' fields of work are related to technological research and development on plastic materials & products and its transformation processes.

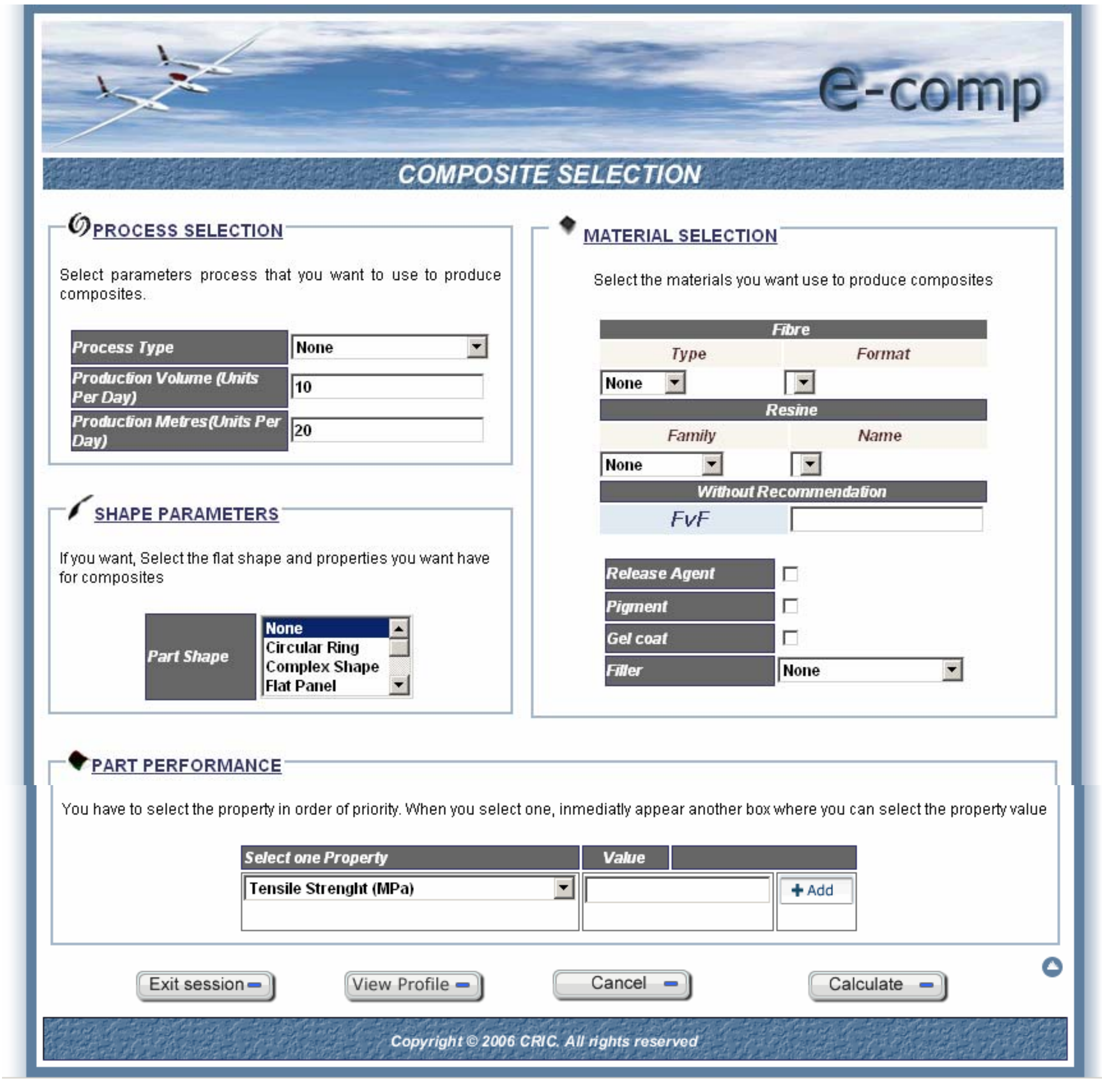
- The BioComposites Centre, University of Wales, Bangor / UK: The BioComposites Centre (BC) was established in 1989 at the University of Wales, Bangor, UK, with the assistance of the Welsh Development Agency and industry. The Centre has an international client base, an annual turnover of £1.2M and is ISO9002 registered. The aim of the Centre is to provide world leading fundamental and applied research into products and processes, based upon wood, industrial crops, recycled materials and industrial residues and to transfer these technologies to industry.

- Pera Innovation Ltd / UK: Pera has grown from the Production Engineering Research Association of Great Britain, and is a technology research and development organisation with high levels of expertise and facilities. Pera is a non-profit distributing Company, limited by Guarantee, and owned by its 1,000 SME Members. Operating for over 50 years as a non-IPR holding business, its Constitution dictates that it should generate and transfer new technology to manufacturing industry.

3. System Description

3.1. Instructions of use

Ecomp input screen shows the following aspect. This is the main input to the Ecomp system, and allows different kind of queries to the system by means of the use of the different input fields.



The different fields are described:

- Process Selection:

  With this field, different processes can be selected. Once the process is selected, only is activated the adequate “Production” field for the selected process. For example, for Hand Lay Up process only the “Production Volume (units per day)” is available, meanwhile for a process such as Extrusion the "Production Metres (Units per Day)" is activated and the previous one is deactivated, because the production for a process such as Extrusion only has meaning with the production expressed in meters.

If NO process is selected, the system will try to suggest the more adequate process for the needed characteristics indicated by the user. For the internal calculus in order to select the suitability of the process for the needs of the user, the production value either in "units per day" or "meters per day" will be used when necessary.

- Shape parameters:

  Once a shape is selected, fields for the corresponding adequate measures input for such a piece are presented. ALL the shapes are always available for ALL the different processes. This is done on purpose, because in this way the user will see if the shape is suitable or not for the process.

- Material Selection:

  The user can select the different resins and fibres when needed. When a material is selected, then the rest is properly filtered (for example, when a resin is selected, only the suitable fibres for that resin will be possible to be selected). Added to this, common additives such as catalysts are included in the resin prize in the output. Other additives such as fillers or release agents can be selected by means of a check box.

- Part performance:

  A number of properties for the final piece can be specified in this box. Different properties are shown and can be selected by means of the introduction of a minimal value for that property. Once this is selected, the system will try to select the proper materials in order to meet the properties minimal values or the system will evaluate if the selected materials meet the introduced values of the properties.

- FVF:

  Fraction Volume Fibre or Fraction Weight Fibre is an input to the system, depending on the selected process. A recommended range is shown. If not entered by the user, the system will use a default value for the FvF dependant on the Process and materials selected.

3.2. Input types:

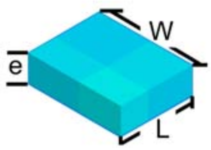
The user, with this type of inputs, can ask to the system for different possible composites expert information, based on the inputs selected and the inputs left in blank:

Inputs	Obtained Output
Material	Suitability Properties Processes
Shape + Rank production	Suitability Properties Processes Two material combinations for each process Costs
Properties	Suitability Properties Processes Materials
Process + Material	Suitability Properties
Shape + Material	Suitability Properties Processes Costs
Shape + Process + Materials	Suitability Properties Costs
Properties + Process	Suitability Properties
Material + Properties	Suitability Properties Process
Shape + Properties	***Not valid Input***
Shape + Materials + Process + Properties	Suitability

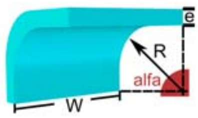
4. Capabilities of the system

4.1. Shapes

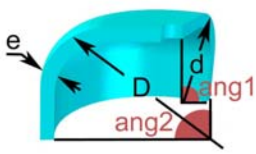
The following shapes are available in the system



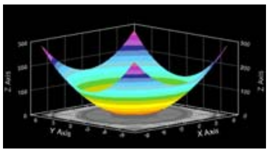
Flat panel



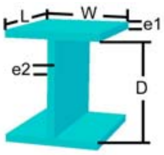
Single Curvature



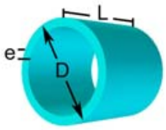
Circular Ring



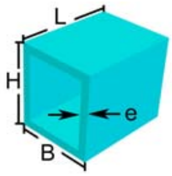
Plan Surface Area



Straight I Profile



Tube



Square Tube

4.2. Supported Materials

Matrix

Polyester- isotophthalic
Polyester-orthophthalic
Epoxy
Vinylester
Phenolic
Polyester orthophthalic formulated by DCPD
Polyester ISO(NPG)
Epoxy vinyl ester
Polypropylene
Polyethylene
Bio-resins Polylactic acid

Fibres

E-Glass	chopped strand mat CSM
E-Glass	continuous mat CFM
E-Glass	Roving
E-Glass	Woven- Unidirectional
E-Glass	Woven-0-90o (E-Glass)
E-Glass	Woven- 0-45^o
E-Glass	hybrid (mat + woven)
E-Glass	hybrid(veil+mat)
E-Glass	hybrid(veil+woven)
E-Glass	Rovicore
E-Glass	Short chopped fibres
Carbon	Woven- 0-90o
Carbon	Roving
Carbon	Woven-Unidirectional
Carbon	Woven- 0-45^o
Aramid	Woven- 0-90o
Flax	Non-woven
Flax	Short chopped fibres

Additives

Pigment	
Fillers	Calcium Carbonate
Fillers	Alumina Tihydrate
Fillers	Antimony trioxide
Fillers	Micro Spheres (solid)
Fillers	Mica
Fillers	Coloidal Silica
Gel Coat	

4.3. Processes Supported by Ecomp

- ☑ Hand Lay Up
- ☑ Spray Up
- ☑ RTM
- ☑ RTM Light
- ☑ Vacuum Bagging
- ☑ Vacuum Infusion
- ☑ Pultrusion
- ☑ Filament Winding
- ☑ Extrusion
- ☑ Injection Moulding
- ☑ Compression Moulding

4.4. Properties supported by Ecomp

- Acid Resistance (value 0 to 1)
- Bases Resistance (0 to 1)
- Chemical Resistance (0 to 1)
- Coefficient of thermal expansion (10-6 ºC)
- Density (g/cm^3)
- Elongation at break (5)
- Fire Resistance (0 to 1)
- HDT (ºC)
- Impact (KJ/m^2)
- Moisture Resistance (0 to 1)
- Surface Finish (0 to 1)
- Temperature Resistance (0 to 1)
- Tensile Modulus (GPa)
- Tensile Strenght (MPa)
- UV Resistance (0 to 1)

4.5. Calculus

Here we present some calculus involved in the whole system. Basically, the composite final characteristics will be the one obtained by the addition of the matrix and the fibres properties.

<u>Weights, Volumes & Prices</u>

(% resin = 1 - FVF) (FVF = Fraction Volume Fibre and indicates the % of fibre contents in volume)
(δFibre = Density of Fibre)

Vol Matrix = Part Volume · (1-FVF)
Vol Fibre = Part Volume · FVF

Weight of Fibre = Vol Fibre · δFibre
Weight of Matrix = Vol Matrix · δFibre
Weight of fillers & additives = Σ Vol Matrix · % (filler or addit) · δ(filler or addit)

Total Weight = Weight Matrix + Weight Fibre + Weight (fillers & addit)

Prices (Fillers & Additives) = Σ Vol Matrix · % (filler or addit) · Price (filler or additive)

Total Price = Weight Matrix · Price Matrix + Weight Fibre · Price Fibre + Prices Fillers & Additives

<u>Properties</u>

The mechanical properties have been calculated with an individual manner with specific formulation. Anyway, if no specific formulation is achievable, the following criteria is used:

Rule of Mixture: Many <u>mechanical</u> Properties (P) in composites, it can be calculated by means of the partial contribution to the whole composite:

Composite_P = FVF · Fibre Prop + (1-FVF) · Matrix Prop

Dependent properties: For some properties is more relevant the resin fibre property solely. In this case the individual property is given, and indicated with "*Depends on resin*" or "*Depends on fibre*"

Minimum of values: In some cases the critical value is the minimum value for the property of the resin or fibre. In this case the minimum is given.

Influence of the Additive into the Composite:

Property = Property without Additive · Additive factor

Suitability:

For the process selection, the final suitability degree of the process for the composite is the product of the different individual contributions.
Example: the suitability of the HLU process for the production of a composite made of Epoxy + Glass Woven 0-90º + Calcium Carbonate (an Additive) is:

Suitability of HLU for Epoxy = 0,7.
Suitability of HLU for Glass Woven 0-90º = 1,0.
Suitability of HLU for Calcium Carbonate = 1,0.

In this case the final suitability for Epoxy + Glass Woven 0-90º + Calcium Carbonate (an Additive) = 0,7 · 1,0 · 1,0 = **0,7**

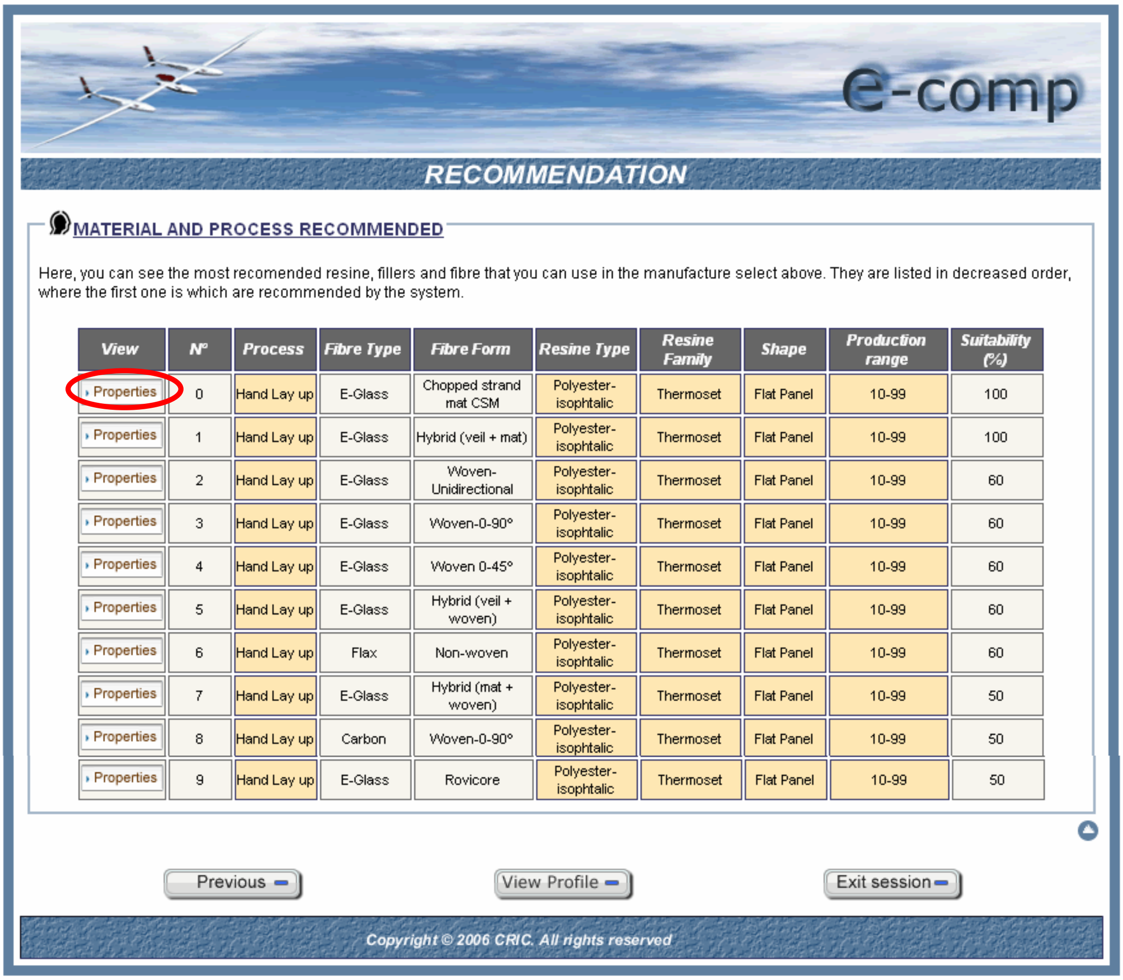
Finally, the processes are ordered from upper to lower and the tops are selected.

In the next table, the different calculation procedures for each property are described.

Properties	**Formulation**
Tensile Strength (tensile_st) (MPa)	Ts=(beta*ts (fibre)*FVF)+(ts_matrix*(1-FVF))
Tensile modulus	Ts_mod=beta*FVF*mts (fibre)+(1-FVF)*mts (resin)
Elongation at Break	Minimum of values
Impact	Rule of mixture
HDT	Depends of the resin, resin HDT increased in 15% (Resin_HDTx1.15)
Density	Rule of mixture
Surface finish	Depends on resin
Fire resistance	Depends on resin
Chemical resistance	Depends on resin
Moisture resistance	Depends on resin
Temperature resistance	Depends on resin
Acid Resistance	Depends on resin
Bases Resistance	Depends on resin
Coefficient of thermal expansion	Rule of mixture
UV Resistance	Depends on resin
Environmental/ Sustainability	Minimum of values

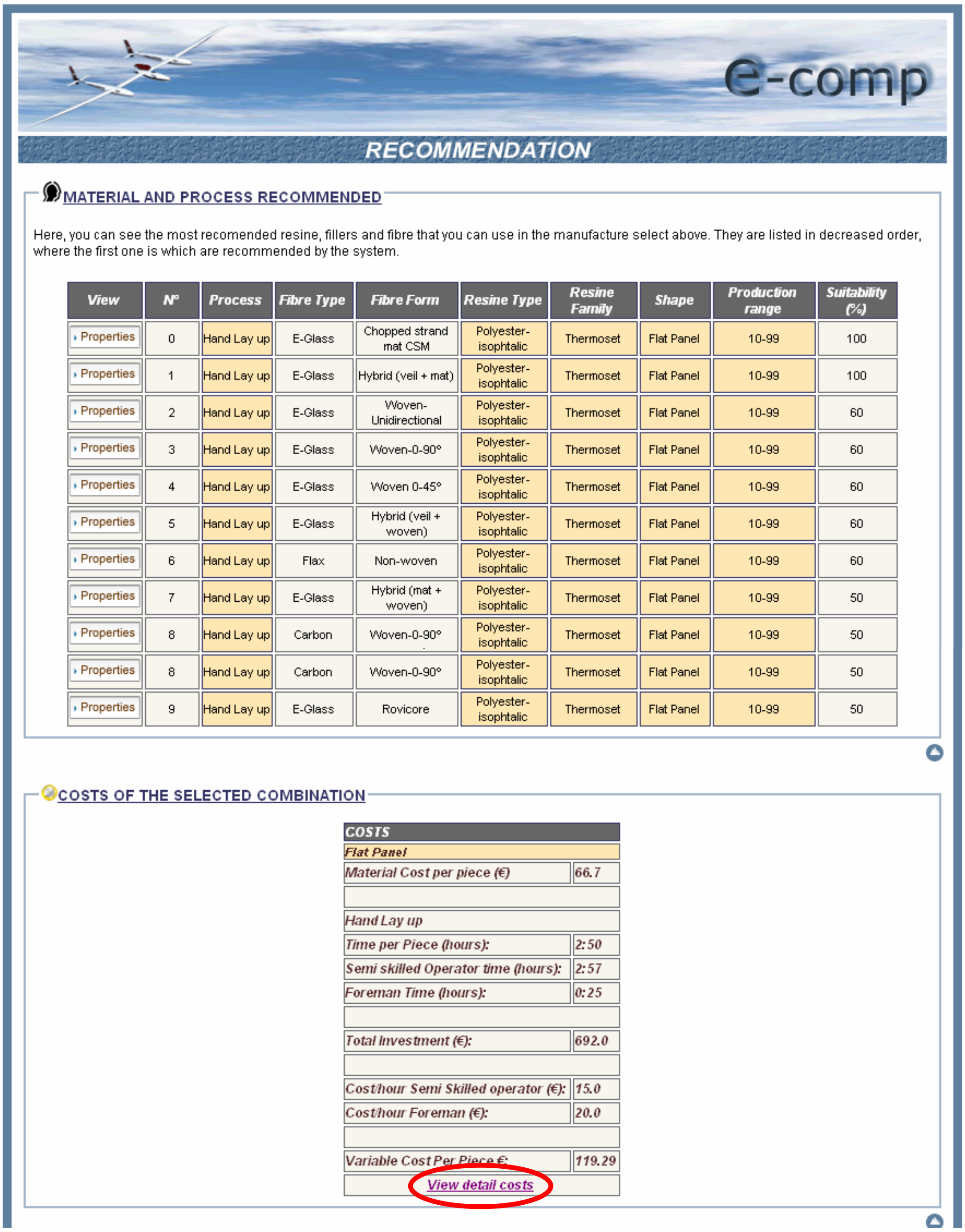
5. Output of the system

The output screen presents the resulting data based on the different input fields entered by the user. Each line represents a combination of processes, materials, production volume, properties and shape that meets the user's input, ordered by suitability of the combination. The fields specified by the user in the input are shown in orange, but all the fields of the combination are shown. At the end of each line, a Suitability degree (0-100) for the combination is shown.



View	Nº	Process	Fibre Type	Fibre Form	Resine Type	Resine Family	Shape	Production range	Suitability (%)
Properties	0	Hand Lay up	E-Glass	Chopped strand mat CSM	Polyester-isophtalic	Thermoset	Flat Panel	10-99	100
Properties	1	Hand Lay up	E-Glass	Hybrid (veil + mat)	Polyester-isophtalic	Thermoset	Flat Panel	10-99	100
Properties	2	Hand Lay up	E-Glass	Woven-Unidirectional	Polyester-isophtalic	Thermoset	Flat Panel	10-99	60
Properties	3	Hand Lay up	E-Glass	Woven-0-90º	Polyester-isophtalic	Thermoset	Flat Panel	10-99	60
Properties	4	Hand Lay up	E-Glass	Woven 0-45º	Polyester-isophtalic	Thermoset	Flat Panel	10-99	60
Properties	5	Hand Lay up	E-Glass	Hybrid (veil + woven)	Polyester-isophtalic	Thermoset	Flat Panel	10-99	60
Properties	6	Hand Lay up	Flax	Non-woven	Polyester-isophtalic	Thermoset	Flat Panel	10-99	60
Properties	7	Hand Lay up	E-Glass	Hybrid (mat + woven)	Polyester-isophtalic	Thermoset	Flat Panel	10-99	50
Properties	8	Hand Lay up	Carbon	Woven-0-90º	Polyester-isophtalic	Thermoset	Flat Panel	10-99	50
Properties	9	Hand Lay up	E-Glass	Rovicore	Polyester-isophtalic	Thermoset	Flat Panel	10-99	50

For each line, on the left side, a "Properties" button can be pressed, and full information for that specific combination is shown. In the following case, the first line button was pressed:



e-comp

RECOMMENDATION

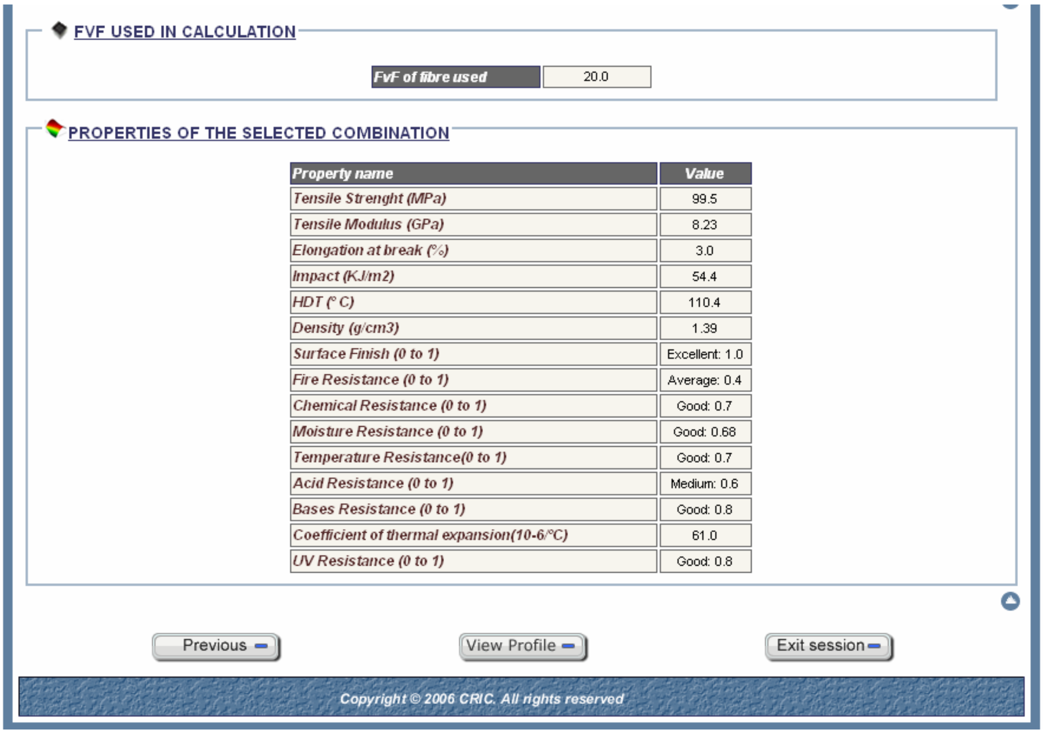
MATERIAL AND PROCESS RECOMMENDED

Here, you can see the most recomended resine, fillers and fibre that you can use in the manufacture select above. They are listed in decreased order, where the first one is which are recommended by the system.

View	Nº	Process	Fibre Type	Fibre Form	Resine Type	Resine Family	Shape	Production range	Suitability (%)
Properties	0	Hand Lay up	E-Glass	Chopped strand mat CSM	Polyester-isophtalic	Thermoset	Flat Panel	10-99	100
Properties	1	Hand Lay up	E-Glass	Hybrid (veil + mat)	Polyester-isophtalic	Thermoset	Flat Panel	10-99	100
Properties	2	Hand Lay up	E-Glass	Woven-Unidirectional	Polyester-isophtalic	Thermoset	Flat Panel	10-99	60
Properties	3	Hand Lay up	E-Glass	Woven-0-90º	Polyester-isophtalic	Thermoset	Flat Panel	10-99	60
Properties	4	Hand Lay up	E-Glass	Woven 0-45º	Polyester-isophtalic	Thermoset	Flat Panel	10-99	60
Properties	5	Hand Lay up	E-Glass	Hybrid (veil + woven)	Polyester-isophtalic	Thermoset	Flat Panel	10-99	60
Properties	6	Hand Lay up	Flax	Non-woven	Polyester-isophtalic	Thermoset	Flat Panel	10-99	60
Properties	7	Hand Lay up	E-Glass	Hybrid (mat + woven)	Polyester-isophtalic	Thermoset	Flat Panel	10-99	50
Properties	8	Hand Lay up	Carbon	Woven-0-90º	Polyester-isophtalic	Thermoset	Flat Panel	10-99	50
Properties	8	Hand Lay up	Carbon	Woven-0-90º	Polyester-isophtalic	Thermoset	Flat Panel	10-99	50
Properties	9	Hand Lay up	E-Glass	Rovicore	Polyester-isophtalic	Thermoset	Flat Panel	10-99	50

COSTS OF THE SELECTED COMBINATION

COSTS	
Flat Panel	
Material Cost per piece (€)	66.7
Hand Lay up	
Time per Piece (hours):	2:50
Semi skilled Operator time (hours):	2:57
Foreman Time (hours):	0:25
Total Investment (€):	692.0
Cost/hour Semi Skilled operator (€):	15.0
Cost/hour Foreman (€):	20.0
Variable Cost Per Piece €:	119.29
View detail costs	



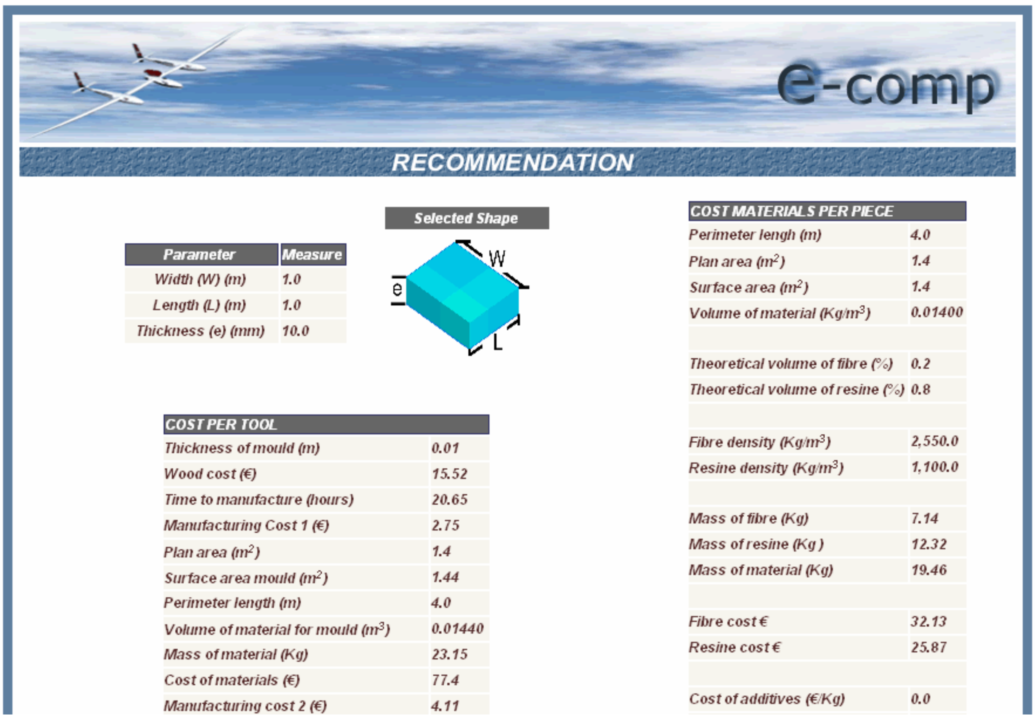
FVF USED IN CALCULATION

FvF of fibre used	20.0

PROPERTIES OF THE SELECTED COMBINATION

Property name	Value
Tensile Strenght (MPa)	99.5
Tensile Modulus (GPa)	8.23
Elongation at break (%)	3.0
Impact (KJ/m2)	54.4
HDT (° C)	110.4
Density (g/cm3)	1.39
Surface Finish (0 to 1)	Excellent: 1.0
Fire Resistance (0 to 1)	Average: 0.4
Chemical Resistance (0 to 1)	Good: 0.7
Moisture Resistance (0 to 1)	Good: 0.68
Temperature Resistance(0 to 1)	Good: 0.7
Acid Resistance (0 to 1)	Medium: 0.6
Bases Resistance (0 to 1)	Good: 0.8
Coefficient of thermal expansion(10-6/°C)	61.0
UV Resistance (0 to 1)	Good: 0.8

After this information, a detailed cost production can be obtained when pressing the *"View detail costs"* link:



Parameter	Measure
Width (W) (m)	1.0
Length (L) (m)	1.0
Thickness (e) (mm)	10.0

COST PER TOOL	
Thickness of mould (m)	0.01
Wood cost (€)	15.52
Time to manufacture (hours)	20.65
Manufacturing Cost 1 (€)	2.75
Plan area (m^2)	1.4
Surface area mould (m^2)	1.44
Perimeter length (m)	4.0
Volume of material for mould (m^3)	0.01440
Mass of material (Kg)	23.15
Cost of materials (€)	77.4
Manufacturing cost 2 (€)	4.11

COST MATERIALS PER PIECE	
Perimeter lengh (m)	4.0
Plan area (m^2)	1.4
Surface area (m^2)	1.4
Volume of material (Kg/m^3)	0.01400
Theoretical volume of fibre (%)	0.2
Theoretical volume of resine (%)	0.8
Fibre density (Kg/m^3)	2,550.0
Resine density (Kg/m^3)	1,100.0
Mass of fibre (Kg)	7.14
Mass of resine (Kg)	12.32
Mass of material (Kg)	19.46
Fibre cost €	32.13
Resine cost €	25.87
Cost of additives (€/Kg)	0.0

Manufacturing cost 2 (€)	4.11
COST MOULD (€)	150.43

TOOLING COST	
TOOLING	22.57

TOTAL INVESTMENT	
TOTAL INVESTMENT (€)	173.0

Component cost considering production volume	
Production volume rating (parts/day)	10
Number of pieces/day for one mould	3.0
Necessary number of moulds	4.0

TOTAL INVESTMENT WITH MOULDS	
TOTAL INVESTMENT WITH MOULDS(€)	692.0

Cost of additives (€/Kg)	0.0
% of additives	0.0
Total cost of additives (€)	0.0
Sub total cost (€)	58.0
Scrap (15 %)	8.7
MATERIAL COST	66.7

LABOUR COSTS	
PROCESS CALCULATED DATA	
Mould preparation time (min)	0.98
Material preparation time (min)	1.69
Lay-up time (min)	48.92
Wet out time (min)	97.84
Polymerization time	20.0
De-mould time (min)	1.0
TIME/PART min	170.43
time (hour)	2:50
LABOUR AND OVERHEADS CALCULATED DATA	
Mould preparation time (min)	0.98
Material preparation time (min)	1.69
Lay-up time (min)	48.92
De-mould time (min)	1.0
Trim time (min)	26.67
OPERATOR TIME	177.1
time (hour)	2:57
LABOUR AND OVERHEADS CALCULATED DATA	
Supervision time (mins)	25.56
OPERATOR TIME	25.56
time (hour)	0:25

Accept