AVPRO-LBR.5, AN INITIAL DESIGN SOFTWARE SUITE WITH SCANTLING OPTIMIZATION CAPABALITIES.

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Abstract

The need for new types of ships having exceptional dimensions (length, capacity, speed,...), use of new material, advanced hull forms (fast ferries, multi-hulls, ...), etc. points out to the limits of standard design experience. For such vessels naval architects and designers cannot use rules and standards which have been established for conventional ships. They need instead to perform direct and rational analysis of the ship structure using, for instance, finite element analysis (FEA) including 3D coarse mesh model of the entire structure and fine mesh models for the components where stress concentration is expected. Nevertheless, in the earliest design stage these powerful tools are not effective.

Computer software in ship design is now commonly used by Naval Architects from the Basic Design stage to the Detailed Analysis but there is still a lack of such tools for Initial Design. At that stage, the available time is too short to use complex and specialized software. The designer usually relies mostly on experience and statistical data to perform the initial design assessment. AVPRO and LBR-5 are two examples of new initial design tools, which have been integrated into a new suite for this early stage of design.

AVPRO is a preliminary design software dedicated to the naval architect. It is used to initiate the first iteration of the design: hull form, mid-ship section, stability, propulsion assessment, general ship arrangement and weight estimates are defined within a short timeframe, albeit in a rough form, using this software. AVPRO algorithms are based on first principles as much as practically possible, thus offering a rational design solution rather than an empirically derived one. This approach offers significant advantages when dealing with innovative designs.

LBR-5 helps designers and builders lowering building costs and perform structural optimization at the earliest design stage. It provides optimum hull girder scantlings within a reduced time (plates, stiffeners, frames, etc.). The objective function of the optimization process is the minimum production cost or the least weight.

This paper discusses how these new tools are capable of bringing a more thorough and complete design assessment in the earliest stage of design.

Keywords: Ship Design, Initial Design Software, Structure Optimisation, Production Cost,

1- COMPUTER TOOLS IN SHIP DESIGN

Computer tools have become an essential part of the ship design office. Their use is now systematic in the development of a ship design, at least in the basic and detailed phase of design. In these stage of the design, the man-hours involved are such that efficient computer tools have greatly improved the time necessary to develop the design.

Typically, we find the following suites of design tools in most ship design offices:

- Hullform development tools, often complete with hydrostatic and stability analysis modules
- CAD system, which serve to produce drawings, starting from the General Arrangement to hull structure and schematics, etc...
- FEA tools, used at least by big shipyards for hull scantling verification and optimization
- CFD calculation tools, which are now commonly used to evaluate seakeeping, maneuvering and optimize hull lines in way of resistance and powering

These tools are most often used by specialists who have significant training and experience in one domain. They are also most often independent tools and require transfer of data with subsequent loss of information between them. The need for integrating these tools in streamlined suites has now arisen and most shipyards are now specifying their needs in this regard, expecting their future systems to work in a fully integrated and seamless manner. In any case, these tools do require specialists and it is found that bottlenecks often occur when many parallel designs take place which will require a given expertise at the same time.

Figure 1-1 Illustrates the use of various specialized software in the design loop. As can be seen various software, usually not interconnected together, are used to carry out the tasks.

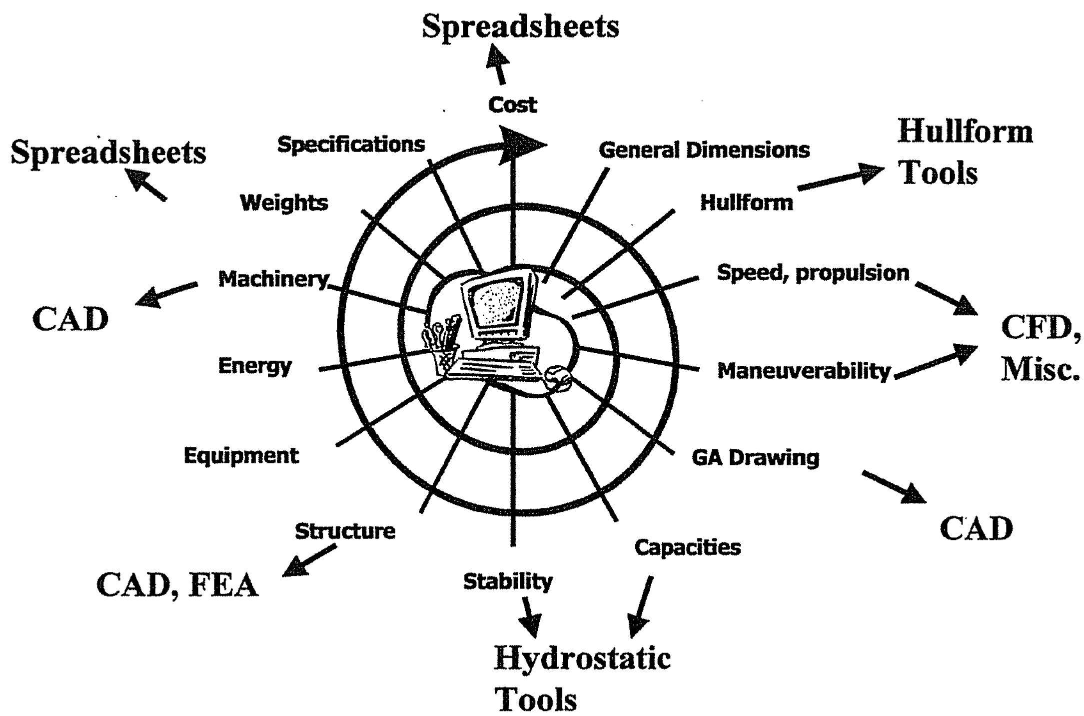

Figure 1-1 Software used in the design loop

2- OVERALL SHIP DESIGN AND STRUCTURAL DESIGN IN EARLY STAGE

Given the time necessary to run specialized software such as those mentioned earlier, and the degree of expertise required for them, the use of these tools is much reduced in the early design stage. The problem is even more pronounced in the very first stage of the design when a rapid answer to the owner's requirements is needed and yet a commitment may be made on the price of the ship, thus necessitating a sound basis for cost estimate (reference [1]).

Figure 2-1 Illustrates the main phases of the design. The tools discussed in this paper address the conceptual and in initial design phases.

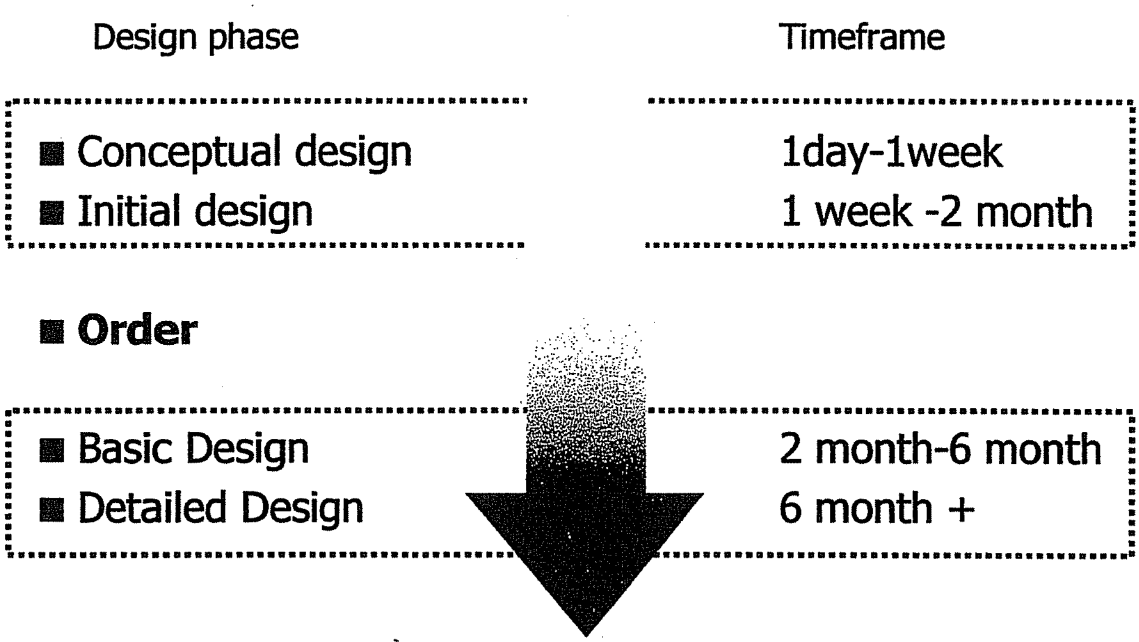

Figure 2-1 Phases of the design

Naval architects usually work with their own spreadsheets and their design experience, often using statistics to make first estimates of the principal parameters which are used in estimating costs, that is:

- hull structure weight
- main areas and volume of accommodations
- lengths of piping, ducts, cables, etc...
- powering estimates
- etc...

The need for software encompassing the basic naval architecture rules is not easy to acknowledge. This profession is rather conservative and reluctant to entrust a software to "do the job for them". However, the issue is not to develop artificial intelligent software but merely to capture the design methodology and help the naval architect formulate his ideas, while checking their feasibility and providing quantified estimates of the parameters mentioned above. The objective here is to replace or second statistical estimate with values calculated form a 3D model. This paper will present a solution developed by Principia Marine to provide an answer to this question: AVPRO (for "Avant-

PROjet" or preliminary design – references [2] and [3]) is described hereafter along with some examples.

Likewise, the structural design is an essential part of the early design. The scantlings will decide the most important part of the lightship weight and will also be critical in defining the labor cost for the shipyard, which is after all the component of the cost for which the shipyard has the greatest latitude of optimizing. A software capable of optimizing the scantlings in order to minimize ship cost in early design is therefore a major improvement compared to current techniques which will rely on few iterations of the midship scantlings along with classification rules verification. An optimization software for hull structure scantlings capable of accounting for many design constraints including rules and standards is therefore discussed as well in this paper: LBR5 is a software developed by University of Liège to such requirements [8]. An detailed presentation of the LBR5 capabilities are presented in a IMDC'03 companion paper [9].

Principia Marine and University of Liège have furthermore engaged in a cooperation to jointly develop these software solutions and integrate them as part of an early design suite. The potential for extending to additional applications is also discussed in this paper. In particular, the use of 3D modeling of the structure and FEA calculations in the early design phase has now become a reality which can greatly enhance the designers work in this phase of the design.

Figure 2-2 illustrates the use of AVPRO and LBR5 in early design. Although the level of precision of AVPRO is not as fine as those software, the ability of this software to handle all the tasks in one single environment provides this tool with a unique capability for early design. AVPRO is completed with LBR5 with regard to structural design. Further into the design phase the 3DPRO methodology enables FEA calculations to be carried out at much earlier stage than is currently the case.

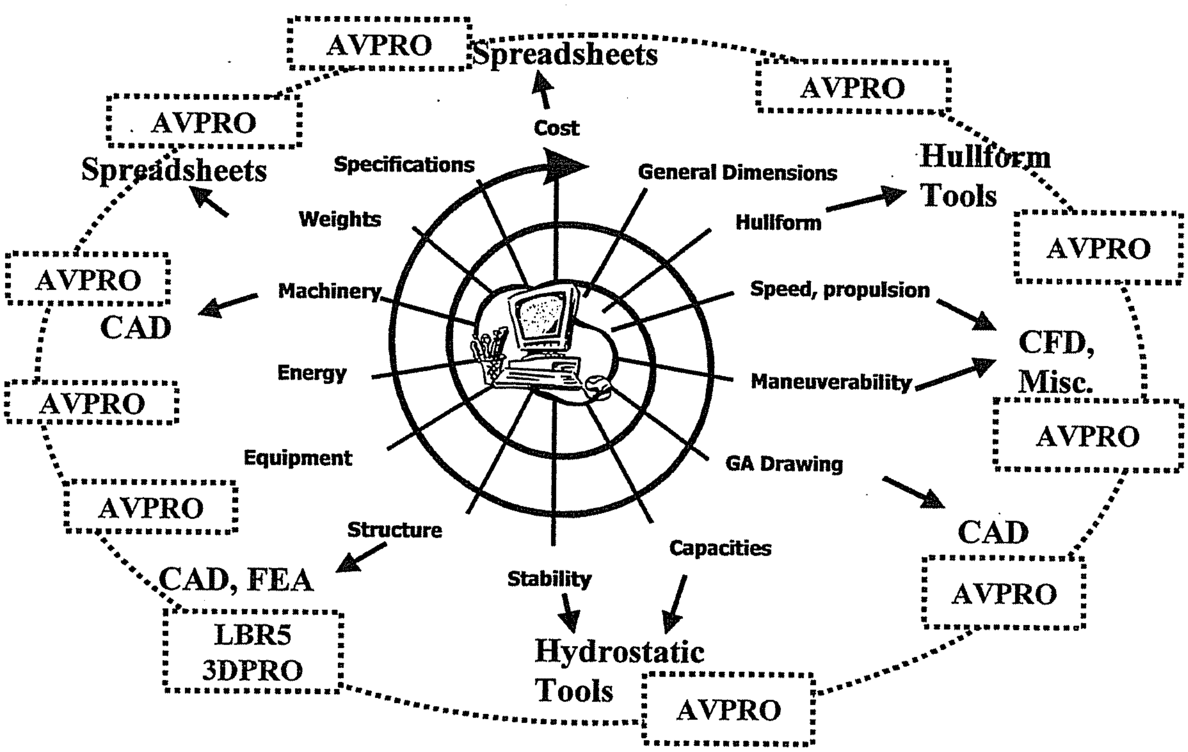

Figure 2-2 Software used in the design loop

3- AVPRO SOFTWARE

As shown earlier in figure 2-2, AVPRO enables the designer to determine the main characteristics of the ship within one single, top-level tool. At each step, the leading particulars are being defined in a first order manner. The typical process used in AVPRO follows the following steps, which can however been reordered as needed and iterated at any time during the fully interactive process:

- The hull and superstructure dimensions are set and preliminary, non-faired hull lines are interactively set in order to achieve the expected displacement, distribution of volumes and hullform coefficients.
- The hydrostatic and stability characteristics are evaluated
- The hull subdivision is determined accordingly (bulkheads position according to floodable lengthy curve and damaged stability)
- The structure scantlings are defined (with the help of LBR5, see next section)
- The main characteristics and position of the propulsion plant components are determined
- The hullform resistance is estimated
- The propulsion plant performance are evaluated
- The general arrangement is defined, again in a top level , not detailed way.
- The subsystem characteristics are determined
- The main areas of accommodated spaces and lengths of piping, ducts and cables are estimated based on the general arrangement and geometry.
- The weights and center of gravity are also estimated based on the general arrangement and geometry.
- The cost can be assessed based on the elements determined above

All of these steps are conducted interactively with few inputs related to the geometry, the arrangement configuration and the type of systems retained.

Figure 3-1 illustrates the various stages of an AVPRO design. In this example, a RoPax vessel was designed with requirements for 2000 passengers and 2000 m-lane while a service speed of 38 knots was imposed. These requirements required new solutions not found in current state-of-the art. A preliminary design was carried out using AVPRO and then developed further using more conventional design methods and tools. The advantage of AVPRO was to focus very rapidly on a set of dimensions, hull lines and general arrangement and propulsion arrangement configuration which were adequate for the requirements, thus limiting the iterations later on.

The basic philosophy used in the AVPRO software consist in using first principles algorithms as far as practicable. This enables the designer to more readily develop innovative solutions than the more classical methods of state-of-the-art based, empirical algorithms or even statistics typically used at such stage of the design. Similar philosophy has been successfully applied to whole ship design synthesis models such as described in reference [4] and [5].

However these tools were intended for wide ranging parametric optimisation of the ship principal characteristics, whereas AVPRO provides a further step towards a practical solution to the requirements. In particular the geometry and arrangements are defined more precisely in AVPRO, thus providing a head-start into the following phase of the design.

Although a more geometry based early design was also proposed by Danan in reference [6], the tool develop in this case was based on empirical algorithms which were in addition very specific of Ro-Pax vessels. By contrast, AVPRO has been successfully used in applications ranging from Ro-Pax and passenger vessels to military vessels, from luxury yachts to LNG vessels. Although specific aspects are addressed in each case, either via specific inputs or by ship type sensitive algorithms, the use of first principle algorithms permits more readily developing such applications.

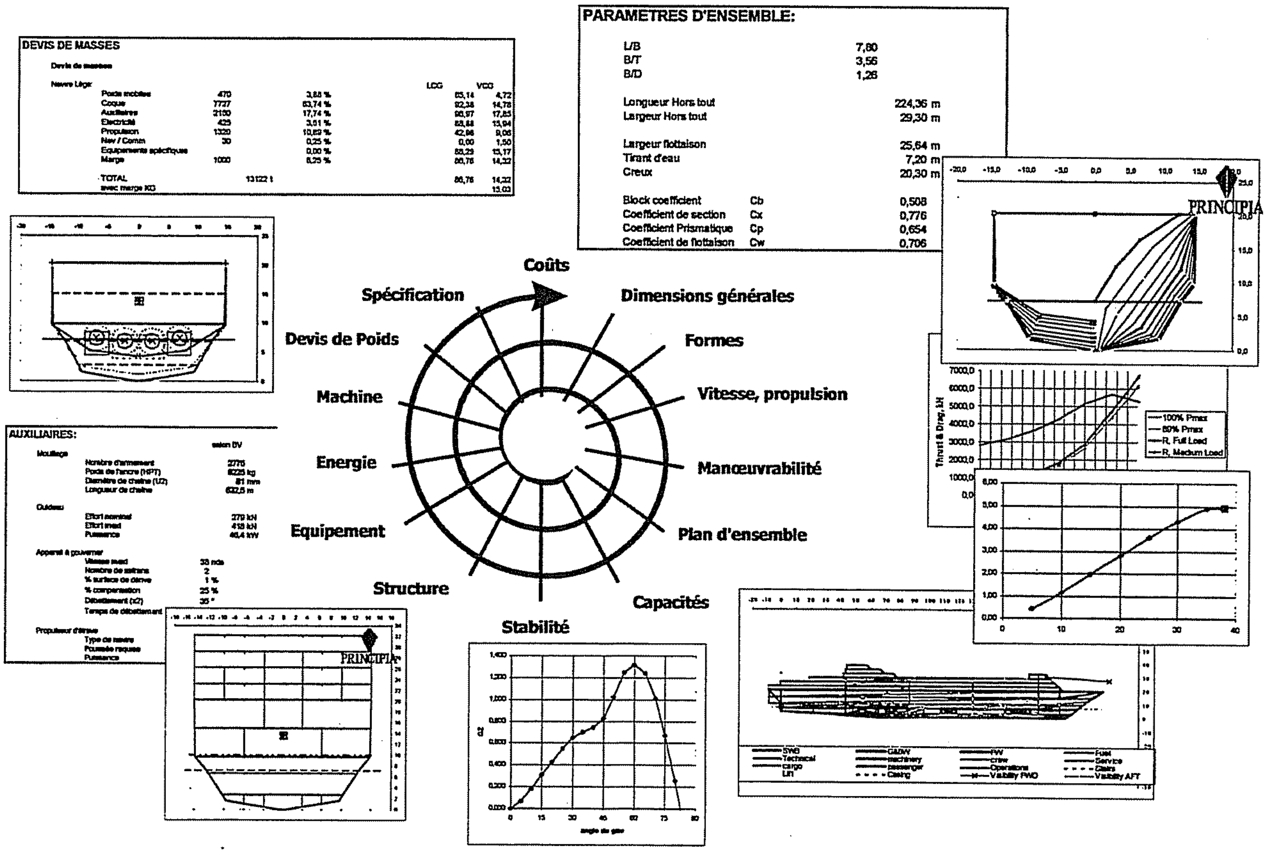

Figure 3-1 Example of AVPRO design

Figure 3-2 illustrates various applications of AVPRO, showing the wide ranging possibilities of such a tool

Finally, another interesting approach to early ship design is that based on genetic algorithms (reference [7]). This method enables reproducing the classic methods used by most shipyard, learning from prior experience to build new, more optimised solutions. However, this is merely an extensions of such methods and cannot provide a basis for breaking with prior art and developing truly innovative solutions.

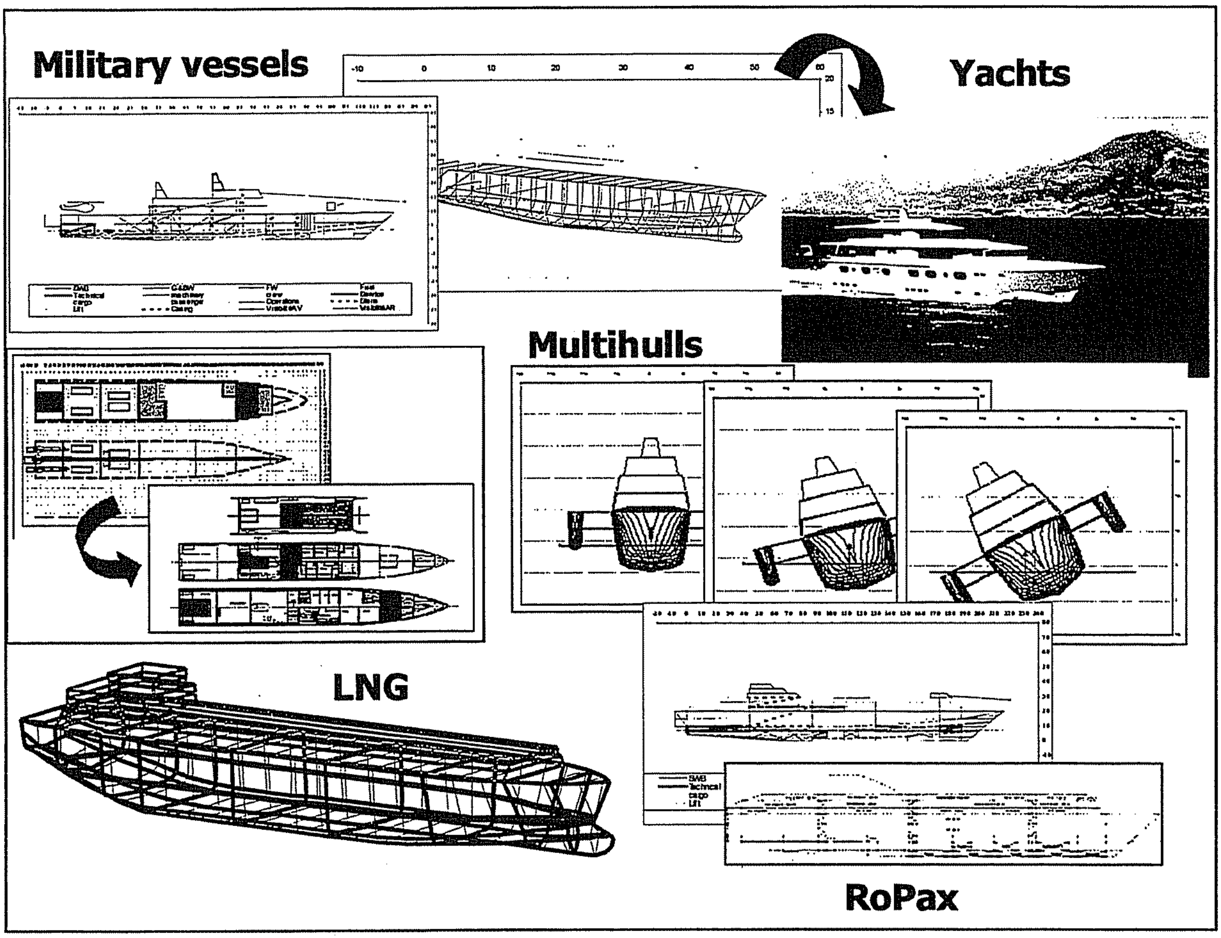

Figure 3-2 AVPRO range of applications

4- LBR5 SOFTWARE

LBR5 is a rational optimisation design module that provides optimum mid-ship scantlings (plating, longitudinal members and frames). Only basic characteristics is required. It is not necessary to provide a feasible initial scantling. Within about 1 hour of computation time with a usual PC, LBR-5 provides automatically rational optimum scantlings of the structure's constituent elements. In the early stage of design, its main advantages are ease of structural modelling, rapid 3D rational analyses of a ship's hold, and scantling optimisation.

LBR5 is built around three basic modules, respectively, *OPTI*, *CONSTRAINT* and *COST* (Figure 4-1). The OPTI module contains the mathematical optimisation algorithm to solve non-linear constrained optimisation problems. The CONSTRAINT module includes (1) technological constraints (or side constraints) that provide the upper and lower bounds of the design variables; (2) geometrical constraints that impose relationships between design variables in order to guarantee a functional, feasible and reliable structure. They are generally based on "good practice" rules to avoid local strength failures (web or flange buckling, stiffener tripping, etc.), or to guarantee welding quality and easy access to the welds; (3) structural constraints that represent limit states in order to avoid yielding, buckling, cracks, etc. and to limit deflection, stress, etc. In the COST module the objective function is the construction cost that includes labour costs and material cost.

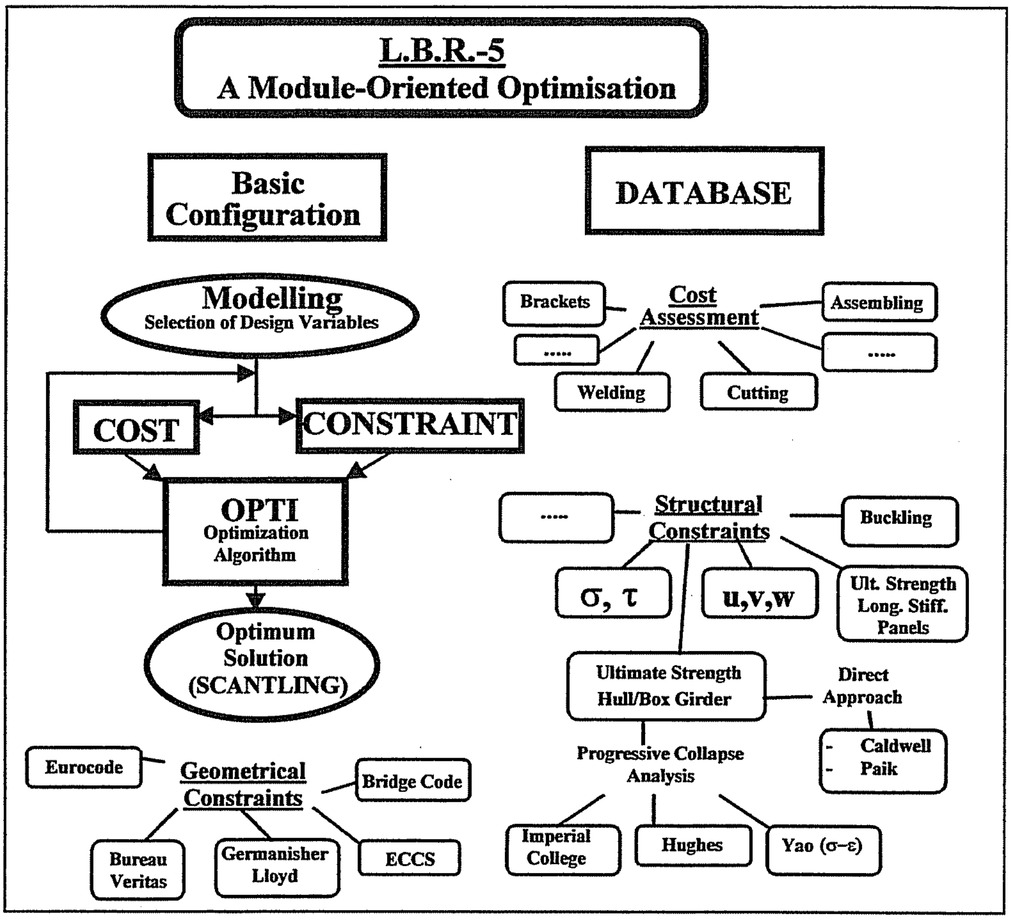

Figure 4-1 Basic configuration of the LBR-5 model and basic modules

LBR-5 is also an efficient tool to assess and compare different alternatives [9]. For instance figure 4-2 gives the cost and the weight as functions of the web-frame spacing.
Other major capability of the method is to quantitatively assess a change of the production technology on the construction cost. For instance, effect of an improved welding procedure (lower unitary welding cost) can be assess by comparing the least cost optimum scantling obtained with and without the improvement.

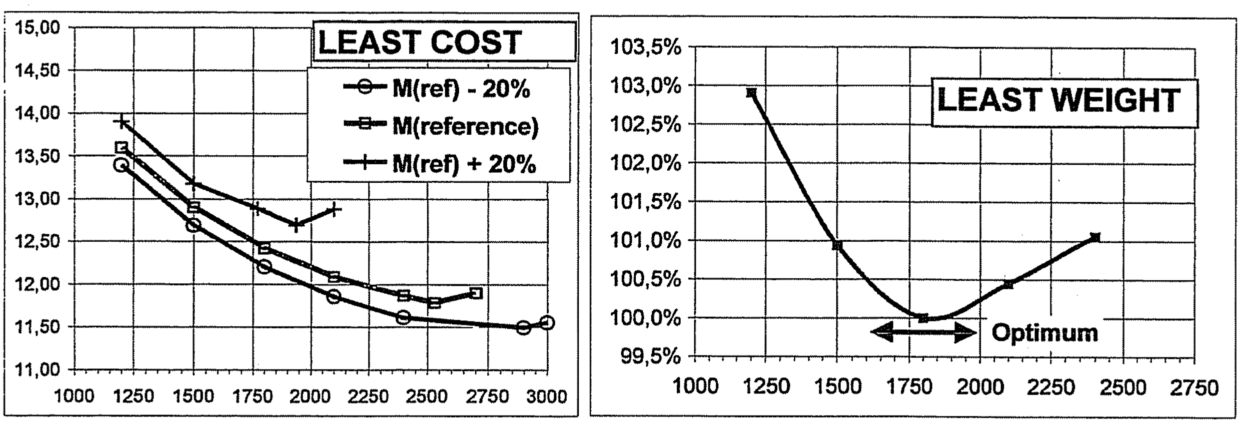

Figure 4-2: Sensitivity analysis: Cost and weight as a function of the web-frame spacing.

Figure 4-3 (left) shows the simple and fast mesh modelling methodology used by the LBR-5 software to optimize a fast ferry (right), which may latter be modelled using standard finite elements (for advanced analysis).

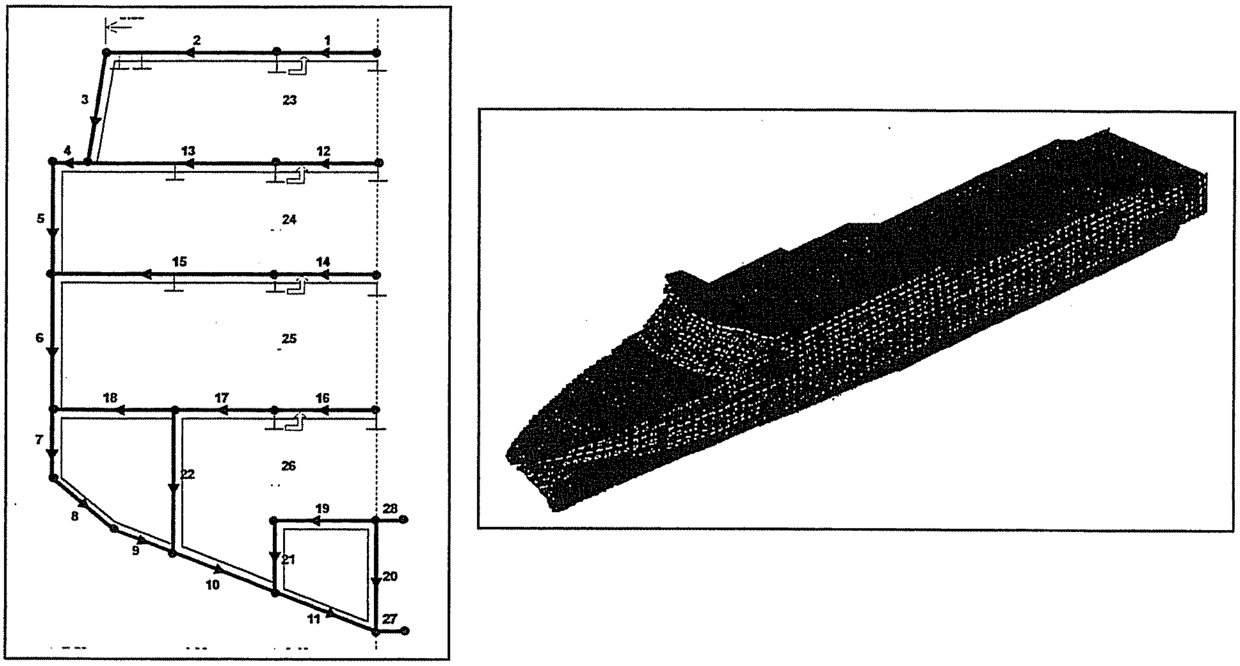

Figure 4-3 : LBR-5 Mesh model of a fast ferry (Corsaire)

5- CONCLUSIONS AND FUTHER DEVELOPMENTS

The two software described in this paper are being integrated into a suite for early design. As a preamble, it has been verified that LBR5 can be executed on the basis of information generated by AVPRO (regarding midship section geometry, initial scantlings, design loads and design constraints). This requires the use of a number of standard assumptions and settings for the optimisation, which are compatible with an early design stage. The implementation of the connection is now planned and will be carried out as part of a joint development effort between Principia Marine and University of Liège.

AVPRO will be able to set LBR5 inputs and run it in the background, LBR5 optimized scantlings will be fed back to AVPRO, enabling the designer to select the most adequate set of scantlings using his experience, LBR5 results and the minimum scantlings from classification society rules. In addition AVPRO will generate automatically input data files for LBR5, thus enabling more detailed analysis and modifications of the standard defaults at a later stage.

Other addition to the structural design segment of AVPRO are also planned in the longer run in order to incorporate new design techniques which have been developed in the recent years, in particular:

- A module for Ultimate Strength analysis
- A module for predicting the first vibration modes of the ship

- 3D Finite Element model in early design

These first two modules already exist as stand alone software and are intended to be connected in a similar way as is being pursued for LBR5.

The third addition exists in fact more in the form of a methodology than a software tool today. The capability of developing early FE Model on the basis of AVPRO and LBR5 data has been demonstrated in a few test cases as illustrated in figure 5-1.

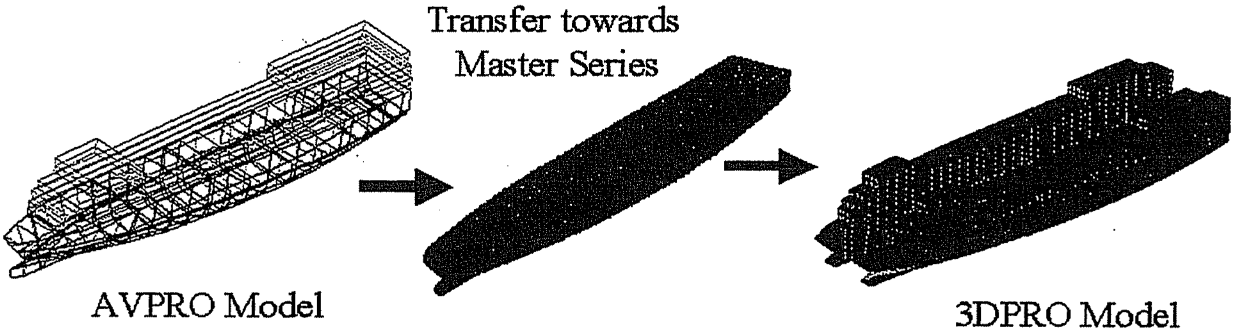

Figure 5-1 Illustration of the 3DPRO methodology applied to a passenger ship

This enables bringing the use of FEA in the early design stage and thus; for the first time use the results of FEA as part of the early design iteration loop, as illustrated by figure 5-2.

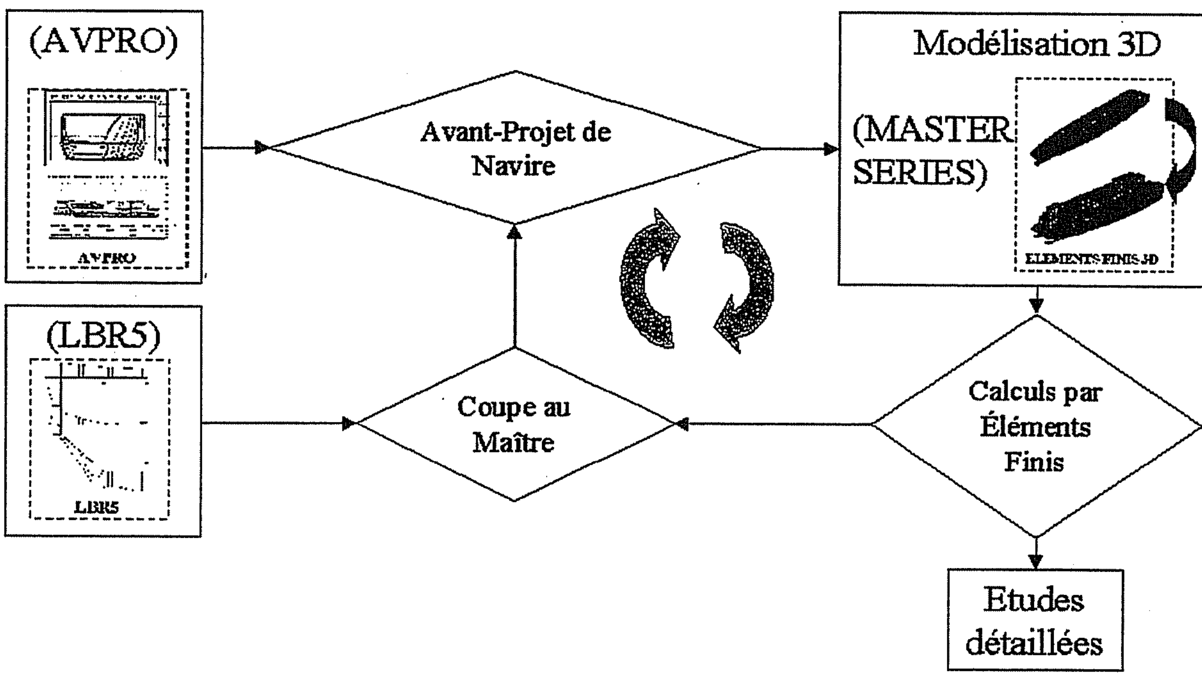

Figure 5-2 Using the FEA in the design loop in early stage of the design

Such achievements are already possible today but still requires a number of user interactions, especially regarding the meshing and verification of the model. The time required to develop an FE model in early design using the 3DPRO method is already compatible however with typical durations of the basic design stage.

The results obtained have demonstrated the usefulness of the method. Although one should not expect being able to obtain as much detailed information as is usually derived from FEA in later stages, the general information provided to the naval architect about the flow of strain in the ship, the deflections and the main zones on concentration of stress are extremely valuable in this stage of the design.

Moreover, this information is available in a phase where it is still possible to iterate the structural concept itself and not merely modify scantlings. Thus the method enables tackling difficulties at a much earlier stage. It is anticipated that development work will be carried out to automate the method and thus render its use more streamlined and pull it into the very first stages of the design (i.e. initial design)

6- ACKNOWLEDGMENTS

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