Wither now the Design Building Block (DBB) Approach

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ABSTRACT

A description of the Design Building Block approach (DBB) was first published at IMDC1997, followed by a practical realisation presented at IMDC2003, both emphasised 3D as a key element of dialogue and creativity in early ship design. The current article celebrates, at the 15th IMDC, this architecturally driven ship synthesis approach with an overview of its fundamentals, followed by a suggestion for an open, collaborative and web-based implementation, and then provides examples that can be used when teaching the approach in ship design. The paper's first part covers the basics of this UCL-developed method, with an overview of the processes, terminology, flow of ship design information, key analyses and key examples published in the literature. The second part focus on an initial attempt to compile a version of this method that can be adapted and implemented in other academic environments, outside the original scope, which was focused on the early stage design of a range of innovative naval vessels. This part of the paper includes an extension of the current taxonomy to commercial vessels, as well as an adapted approach that can be used for ship design teaching and research. Additionally, a compilation of open online stepwise examples is presented, using the NTNU-developed web-based library Vessel.js. These examples cover the basic steps to teach the use of and to readily modify DBB for environments outside the constraints more applicable to multirole naval vessels. The paper concludes with a summary of its main intentions, emphasising the current gap that it is seen to fulfil by compiling the key DBB derived information in a single document. This is then followed by open and online examples that can be readily accessed, modified and expanded.

KEY WORDS

Computer aided ship design (CASD); Design Building Block (DBB) approach; Early Stage Ship Design (ESSD) of service vessels; 2D and 3D modelling; Teaching Ship Design.

A (NOT SO) SHORT STORY OF THE DESIGN BUILDING BLOCK METHOD – WHY IT FOSTERS INNOVATION

Introduction

DBB has been explained in many previous papers, here at IMDC and pretty much most of other important maritime conferences and journals, by our preeminent co-author, David. J. Andrews, or by one of his colleagues and students. When the first author proposed the idea of this paper to the third, the core objective was to extract the key elements that makes the DBB one of the few ship design approaches able to produce real innovative designs from the start. DBB has at its core facilitating creative innovation in the *inside-out* conception and so was proposed with future CASD features in mind. In other words, DBB starts with a colour coded, visual and hands-on approach. It starts with the architectural mindset. Consequently, the validation and evaluation of the goodness of the design are part of the intent as was the fact that the ship model could be readily changed.

From the requirements elucidation, (Andrews, 2003a; 2011), overall sketches and formalisation of design margins via the, DBB approach pushes the designer to draw conceptual assemblies which, with modern 3D tools, can be *Lego-like* to

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explore the infinite space of ship arrangements. One may argue that this can be risky, as by stepping out of the traditional reliable evolutionary zone of designs, we are incorporating uncertainty and less knowledge, which may be true. But by having a new ship with at best incremental changes from previous designs, we also have made a stylistic choice in being constrained by the limitations from decisions made decades ago, and thus stagnating the field of ship design. Stagnation, imitation, replication thus oppose any possible Innovation.

It is thus a matter of style (5^{th} of the S^5 the traditional focus of the naval architect on the aspects of Speed, Seakeeping, Stability, Strength and additionally that of Style - see Figure 1 and Table 1 in Andrews, 2017) in trading off innovation (and risk) against stagnation (and reliability) during ESSD. At one end of the spectrum, we can skip innovation and just copy the last ship, and we will possibly end up with a reliable, functional and cheap, and existing design. It might (if we are lucky) perform the mission, through the outdated solutions and limitations of the chosen previous design. This *shelf to order* (StO) solution is the bread and butter of ship design, since the majority of commercial ships are designed with functionality and reliability in mind, not innovation.

In this sense, most of the ship design methods taught need to cover the last approach, as starting from a Type Ship/reference ship and making incremental changes to it, which is a useful way to introduce the students to the terminology, trade-offs and challenges of the ship design task. This, however, hinders innovation and, in our personal opinion, removes also the joy of our craft. A young student that chooses naval architecture in her earlier years is attracted by the challenge of constructing large and unique artificial systems, including the freedom to draw, create and explore. We teachers, however, quite soon put aside all of it, pushing the students to rules, regressions, spreadsheets. In many cases the drawing, sometimes only a General Arrangements (GA), is done only at the end, only after all the tabular approach that is proposed in so many books and compendia is finished and approved. A ship design course may force a student to spend more time on complying with rules and criteria, typing these into a spreadsheet, than the real designs tasks involving decision making (see Figure 4, Andrews 2018).

The DBB approach does not jump into the design decomposition so rapidly, rather, it spends more time on providing the basis for elucidating the requirements and establishing limits for each requirement, in the shall / should manner. The functional decomposition, at first, is also less detailed than in traditional approaches (Rawson and Tupper, 2001), as it rarely covers more than twelve functions in the first approach. Each of these functions are indeed connected to Super Building Blocks (SBB), which, by adding a visual representation, improve on the tabular approach. It does, however, require the blocks, and moreover, it gets the designer to assign specific set colours (i.e. Blue, Red, Yellow and Green) to each of the four functional groups (i.e., Float, Move, Fight/Operation and Infrastructure - see Andrews 2018), thus bringing in the visual element right from the start. The design is then made by parsing these blocks into modern CASD software, connecting it to a certain space definition (e.g., taxonomy, such as cargo, weapons, etc.), geometric definition (main dimensions, decks, compartments, etc.), hullform (enveloping the blocks) and consequently the information consequently necessary for the initial naval architectural calculations, such as weights, centres and materials.

The approach to ship synthesis, prior to the use of computers in initial design, was initially continued using computers to speed up the iterative, weight and space, and (intact stability and power estimating) balancing process. This was followed by the computational facility, to explore a wider range of alternative design inputs and hull form relationships, which had been previously limited by manual methods. However, this early stage exploration was still one of a largely evolutionary nature, with weight group balancing by naval architects and draughtspersons drawing profiles and, occasionally, also deck plans. In 1980 the third author presented a paper to RINA entitled 'Creative Ship Design' (Andrews, 1981). The intention in choosing that title was not to imply that ship design as then practised was not capable of being innovative, but rather to make the point that, if naval architects were to fully utilise the benefits becoming available through the veritable explosion in design methods and creative techniques for dealing with complexity, they would then be better enabled to design even more creatively than hitherto. That early paper suggested that designers should focus more intensely, at the initial design stages, on ship architecture – both internally and on the topsides – than was possible before the advent of computer aids. Even that long ago rudimentary computerised graphics were becoming available to designers, and subsequently advances in computer graphics made such possibilities even more achievable, consequently a 2003 paper entitled: *A Creative Approach to Ship Architecture*, presented a fully achievable architectural emphasis to early stage ship design (Andrews, 2003b).

The Evolution of the Design Building Block approach

The arguments advanced in the 1981 paper led to a research programme into ship design methodology (Andrews, 1984: 1986; 1987; Andrews and Dicks, 1997) and naval ship design and acquisition (Andrews, 1993; 1994; 2013). It was perceived that the evolutionary approach to ship design, typified by so much of existing design approach and built into most design tools, has become progressively less appropriate. The latter aspect can be illustrated by the following observations made in the 2003 paper:

a) Dependence on an evolutionary approach is less likely to lead to the production of designs responsive to the accelerating rate of change (Andrews, 2001a), whereas a creative design approach enables exploration of responsive and adaptable design options (Andrews, 2001b);
b) Potentially better solutions, such as the Trimaran configuration (Andrews, 2004), are unlikely to be considered in an evolutionary approach, while many of the techniques now available are conducive to the search for and development of novel solutions;
c) These new techniques, in conjunction with a creative approach, are practically indispensable for adequately coping with what has been termed the 'wicked problem' (Rittel and Webber, 1973). This arises in requirement elucidation when designing complex ships (i.e., requirement formulation and design responses are in a circular relationship).

While a research version of what was denoted as a 'Design Building Block' approach to the design of physically large and complex entities had been demonstrated in the 1998 paper, this was written (Andrews 1998) based on a breadboard demonstration using the developments in computer graphics when presented to the 1997 IMDC by Andrews and Dicks (1997). Already a working version had been produced in the form of a classified system, specifically for naval submarine concept design (SUBCON - Andrews et al., 1996), but it was not until 2001 with Andrews final return to UCL that a more general working system was produced and made openly available. It was then possible to demonstrate the approach could be applied to actual (rather than research) design problems (Andrews and Pawling, 2003, 2008). Since it has now become possible to demonstrate that the DBB approach has matured and can be applied to a large range of design studies *for real* (see Sections 6.2 and 6.3 in Andrews (2018) for outlines of published UCL studies). Moreover, regarding ship design as an example of Design on the Grand Scale, this graphical way of proceeding "inside-out" could provide insights relevant to a more general understanding of design philosophy and design methodology.

Before proceeding with the main body of the paper, it is appropriate to acknowledge that there has been a distinct bias towards naval ships in the examples used to illustrate the DBB based themes. This tendency arises from the third author's career as a naval architect working for the UK Ministry of Defence up to 2000, where he was largely engaged in the design of surface warships and submarines for the Royal Navy. We believe that warship design can be said to have made significant contributions to the discipline as a whole (see Andrews, 2010). This assertion is made even though the timescales and very significant resources, invested in the course of many warship designs, dwarf those invested in even the largest and most complex merchant ships.

While it could be argued that a design procedure capable of addressing such a level of complexity in the most complex of naval vessels should be scalable to suit less complex ship design processes, it is open to debate whether the naval ship design environment is disproportionately "over the top" and so makes the procedure – and the associated design philosophy – inappropriate for application to even the most sophisticated commercial vessels. On the contrary it is considered that all ship design is increasing in complexity and that there are growing synergies between naval and commercial ship design approaches, as instanced by the moves to apply naval ship rules and codes of engineering practice to be managed by the commercial classification societies (Gibbons, 1984). Therefore it has been argued that the creative ship design approach advocated, centred on an architectural schema, has a wider applicability to marine design in general.

As stated in the introduction, the 1980 paper concluded that creativity in ship design would be fostered by an approach to the initial ship synthesis which placed greater emphasis on the physical description of the ship's layout. A subsequent justification for this approach to initial ship sizing was reported in a 1986 RINA paper that followed the third author's PhD (Andrews, 1984), an early naval architecture thesis on ship design methodology.

In the 1984 PhD thesis, entitled "Synthesis in Ship Design", the third author contrasted the sequential process of gross ship sizing, followed by hull parameter determination and then architectural and engineering development with the *all in one* or integrated synthesis. This was subsequently confirmed by development of the Design Building Block approach, firstly in the UK MoD's developed SUBCON CASD tool (Andrews *et al.,* 1996) and then the UCL sponsored SURFCON module in the Paramarine CASD system (Munoz and Forrest, 2002). This combination of the ship architectural and naval architectural balanced numerical description served to provide an ability for the ship designer to develop *ab initio* design options, which could consider many of the main ship requirement drivers from the start of a new design study.

FEATURES OF THE UCL DESIGN BUILDING BLOCK APPROACH

The manner in which the SURFCON tool is structured was described at the 7th IMDC following its beta testing by Andrews and Pawling (2003). Two features are considered worthy of note:

a) A functional breakdown of the design building blocks adopted for ship description. The categories of the building blocks (i.e., float, move, fight/operational and infrastructure) can be distinguished by their four characteristic colours, plus purple for the main access routes (as a subset of the Float function, highlighted because it is seen as key to the ship's internal layout). This breakdown of the Design Building Blocks was introduced to foster the exploration of more innovative configurations as part of Requirements Elucidation (Andrews, 2003a, 2011), where choice of style is the key to synthesising a new ship option.

b) Use of the term Master Building Block to indicate how the overall aggregated attributes of the DBBs would be brought together, to provide the numerical description of the resultant "appropriately balanced" ship design. The audited building block attributes assembled within the Master Building Block (constituting the top-level whole ship description) could be used directly by the Paramarine analytical modules, thereby enabling the necessary naval architectural calculations to be performed to ascertain the balance, or otherwise, of the whole ship configuration being derived by the designer.

Each design building block, as the fundamental component of the SURFCON approach, can be regarded as an object in the design space and as a "placeholder" or "folder" containing all the information relating to a particular function within the functional hierarchy. Importantly the "block definition" object permits the designer to add whole ship margins and characteristics, such as accommodation demands, once the "block summary" object has summarised all the information in the top-level block in the building block hierarchy – this is the Master Building Block object. The "design audit" object then allows the design description to be audited for any of the characteristics selected for monitoring, which typically will include style aspects alongside primary naval architectural capabilities. Results can be displayed using the functional group hierarchy; this "design audit" object is assessed for a range of design infringements, by other objects in the design space, and for the balance of the overall ship design from the whole ship characteristics listed in the Master Building Block.

After the SURFCON initiative finished, the exploration of ship internal configuration has been taken further by the Marine Group at UCL, specially the third author and his UCL colleague Dr. R. Pawling (see Section 6 in Andrews 2018). Firstly, in the exposition of the integration of configuration in ship design (Andrews, 2003b) and subsequently by expounding this approach to the design of ships (and other complex systems) to a wider scientific and technical audience (Andrews, 2012). This led to the realisation of the UCL Design Building Block approach, an integrated approach to ship synthesis, at the commencement of the design process, accomplished by using computer graphics to build up the ship's internal architecture, which can then be used to feed the traditional numerical sizing synthesis. Illustrations of the graphics output, linked to the PARAMARINE balanced numerical ship definition, exemplified the UCL DBB approach and taken from the extensive presentation of the architectural approach to early stage design of complex vessels (Andrews, 2018), are given in Figure 1.

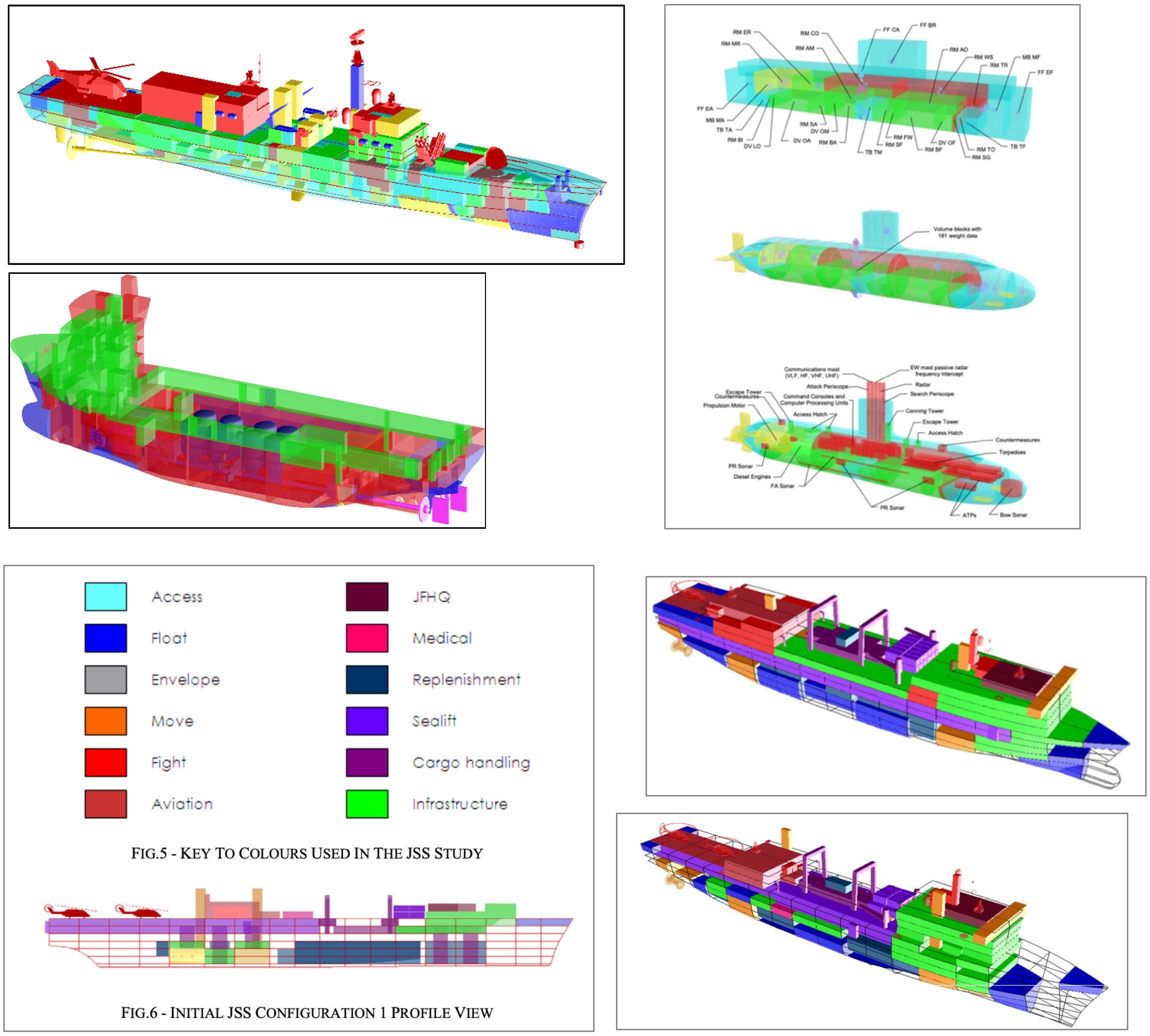


Figure 1 – Examples of Designs made by UCL using DBB method (compiled in Andrews, 2018)

With an architecturally based description at the early stages of a design, it becomes possible to explore many of the issues which are of direct interest to the client/owner and stakeholders. Such issues - ranging from those concerned with naval vessel's fighting capabilities or the service ship's crew evolutions on board, to the sustainability and supportability of the vessel conducting tasks at sea - are best investigated for their impact on the overall design at the earliest exploratory stages of the design. Thus, for example, layout for weapons effectiveness is a function of topside disposition (Gharib, *et al.*, 2016) and also of internal arrangement and zone logic (Piperakis and Andrews, 2014), both of which are more readily explored through the ship's architecture. Zoning is also relevant to survivability concerns and to the logic adopted for routeing ship systems (Mukti, 2022), and these in turn interact with considerations on producibility and constructional building block arrangements. The initial design can also, with this approach, meet the aspirations of concurrent engineering (Keane, 2018) because the initial configuration is able to reflect not just the traditional focus of the naval architectural aspects of the S^4 as performance drivers but also producibility and even through life supportability considerations.

One clear reason why a 3D *inside-out* approach should be adopted in early stage ship design is that many issues that really ought to be addressed, early in design, can then be more easily considered. Given many of the practicalities of major interest to the client/stakeholders are best revealed by the upper decks/internal configuration definitions, then integrating the architecture into initial concepts must be preferable to the somewhat one-dimensional numeric exploration. However, this would counter the evolutionary set of steps in the initial design development and also the ability of the approach to produce, relatively quickly, an architecturally, numerically and analytically balanced design. Thus, an initial crude internal arrangement can be very useful in grasping the major "blocks" of operational, mobility and infrastructure categories and avoids being distracted by too much detail too early. With respect to the time taken to achieve design balance appropriate to concept definition, Figure 1 shows four distinct configurations (plus three variants) for a heavy lift LCS Mothership concept, all with some 200 DBBs and balanced in space, weight, stability and powering (Andrews and Pawling, 2004).

We realise that the DBB approach can be used to discuss the *goodness* of a design in many ways, here summarized (from Andrews, 2022):

a) ***Cost***: By better understanding what is wanted and how it might be achieved, the partners in the process are more likely to understand, early in the process, where are the *knees in the cost-capability curves* and how they can be efficiently exploited, and how ships can be cheaper to construct and or operate in preference toadopting the *smallest* (less effective) design.
b) ***Sophistication***: A more sophisticated initial design approach would be able to both feed the marine design research and development and respond better to research innovation coming the other way, often hard to be revealed by tradition numeric concept design outputs. Quite unlike the aerospace industry, for too long the naval ship design community have accepted that it was possible, and therefore justifiable, to not adequately resource the R&D associated with ship design often reflecting commercial ship acquisition practice (Andrews, 2024). In the sophisticated offshore market (Ulstein and Brett, 2015) and cruise ship practice (Levander, 2015) this has become much more nuanced.
c) ***Holistic implications***: An enhanced DBB type of design approach might then help to recover the ship designer's role as *prime interpares* in the ship design process. This is not trying to recover lost glory but recognition of the naval architect's inherent stance that *everyone else's problems are also the naval architect's, and they can best appreciate the whole ship implications* (Andrews, 2022).

ADAPTING THE DBB APPROACH

As the DBB approach has been mostly taught at UCL, and most of the examples publicly available are naval service vessels, although these include not just combatants and carriers but also naval auxiliaries which are more like commercial tankers and cargo vessels, (e.g., Littoral mothership, Canadian Navy Joint Support Ship see Andrews, 2018), in the rest of this work we took on the challenge of adapting some its core elements to commercial ship design, both service and transportation vessels. In this context, traditional ship design disciplines like stability, resistance, strength and seakeeping (S^4) can be taken out of the scope here, given that these calculations are necessary for any kind of ship, no matter the approach behind its design. Additionally, a better assessment of the ship's centroid, through a DBB description, should improve the initial stability assessment, as indeed would use of DBBs to allocate specific space and weight margins, furthermore, the DBB approach can be used to emphasise stylistic choices. The rest of this paper, thus, focuses on the use of design blocks, that is, this abstract and colourful construction that is the essence of the DBB approach.

We emphasize here some of the elements from the DBB approach that are connected to the fostering of innovative designs. It is important to note that this is a simplification, with the intention of identify the reasoning that leads towards achieving an innovative design culture. For a more detailed description, see references from the previous section.

Table 1 uses the terminology described in IMDC 1997 by Andrews and Dicks, adapted to a more generic description of the ship. In this case, phases like *Weapons and Sensor Placement* becomes *Task Related Equipment Placement*, and *Aircraft Systems Sizing & Placement* is changed to *Payload Systems Sizing and Placement*. Similarly, the block category FIGHT becomes OPERATE. This thus accommodates service vessels, such as Anchor Handling and Towing (winch) and heavy lift (crane), as well as cargo / transport vessel features, such as tanks and cargo areas. The explanation is based on the work of Pawling (2007) and Andrews (2012).

Table 1 – Adapted DBB Stages to ship types beyond naval vessels (preliminary, first attempt)

Adapted DBB Design Stages		Purpose	Output
1	**Design Preparation**		
1.1	Selection of Design Style and Capabilities	- Select type of design in terms of novelty, namely: second (stretched) batch, simple type ship,	Design Framework, containing sketches and sufficient data to start

		evolutionary, simple (numerical) synthesis, architectural synthesis, radical configuration and radical technology (Andrews 2018, Table 3). - Select major style aspects, such as hullform topology and technical design standards. - Key design drivers (e.g. mission and operational profiles) - Identify capabilities required, such as speed, range (autonomy), tasks (mission), payload, crew.	the iterative design process, such as weight and space grouping systems, equipment and subsystems data and validate existing design data. Main design drivers and interactions.
2	**Topside and Major Feature Design Phase**		
2.1	Design Space Creation	- Populating the library of blocks, with geometry and volume definitions, that is, digitalizing the design framework. - Selection of the blocks taxonomy (e.g. FLOAT, MOVE, FIGHT /OPERATION, INFRASTRUCTRE) - Super Building Blocks (SBB) to develop overall layout and spatial style of the design. - Design margins and options - Study of alternative layout styles (parallel development)	Library of SBBS according to the taxonomy. First design definition (layout style) Shall / Should Requirements
2.2	Task Related Equipment Placement	Estimation of size and weight of equipment related to key tasks of the ship (and support crew, if necessary)	SBB blocks for tasks (e.g. FIGHT, OPERATION)
2.3	Engine and Machinery Compartment Placement	Gross machinery size, based on style, type of fuel, estimated resistance and autonomy.	SBB blocks for machinery (e.g. MOVE, propulsion system)
2.4	Payload Systems Sizing and Placement	Gross estimation of payload, like tanks, cargo areas, deck areas	SBB blocks for payload (e.g. FLOAT)
2.5	Superstructure Sizing and Placement	Gross estimation of superstructure size (bridge, accommodation)	SBB for infrastructure and accommodation (e.g. INFRASTRUCTURE)
3	**Super Building Block Based Design Phase (10-20 SBBs)**		
3.1	Composition of Functional Super Building Blocks	Prepare an initial layout according to the taxonomy.	Initial estimation of overall vessel size and displacement Initial hulform (topology) and resistance
3.2	Selection of Design Algorithms	Algorithms, constraints and criteria for preliminary analyses (S4 – stability, speed, strength and seakeeping) Scaling and morphing algorithms (hull)	Models for assessment of S4 criteria
3.3	Assessment of Margin Requirements	Procedure to check if the design with SBBs is within the margin requirement (e.g. shall/should), criteria and constraints.	Procedure for evaluation / auditing
3.4	Placement of Super Building Blocks	Placement of SBBs and creating a layout. Checking for necessary additional spaces (e.g. fuel tanks, auxiliary machinery, ballast tanks). Preliminary (parametric) hullform	Vessel estimation with improved topology, subdivision, and high-level functional zoning. Hullform aspect detailed.
3.5	Design Balance & Audit	Iteration to numerical balance: adjusting current design iteration towards balance and evaluation of the requirements	Balanced design, assessed within the criteria, margins and constraints.
3.6	Initial Performance Analysis for Master B.B.	Limited analyses of S4 performance indicator. Weight and volume demand trade-off and iteration.	Preliminary design, rough layout, Main design drivers revealed. Volume and weight estimated, iterated to satisfy gross margins.
4	**Building Block Based Design Phase (100 - 500DBBs)**		

4.1	Decomposition of Super Building Blocks by function	Decomposition of SBBs into DBBs. Refinement of design into a level of detail that satisfies the designer as to assess the performance within safe assumption of the margins. Volume and/or weight definition and geometry	Design Building Blocks (volume, weight, description).
4.2	Selection of Design Algorithms	Approaches to detail the procedures, constraints and criteria for preliminary analyses (S4 – stability, speed, strength and seakeeping). Algorithms for hullform tunning.	Models for analyse DBBs layout
4.3	Assessment of Margins and Access Policy	Procedure to check if the design with DBBs is within the margin requirement (e.g. shall/should), criteria and constraints.	Procedure for evaluation / auditing
4.4	Placement of Building Blocks	Iterative process of design development, manual and routines. Detailed study of hullform shape.	Vessel estimation with subdivisions and spaces, and low-level functional zoning (pre-GA). Hullform shape detailed
4.5	Design Balance & Audit	Iteration to numerical balance: adjusting current design iteration towards balance and evaluation of the requirements with DBBs	Iteration towards balanced design, with main and support related systems (spaces)
4.6	Further Performance Analysis for Master B.B.	Performance analyses according to the mission and taxonomy (e.g. FLOAT, MOVE, OPERATIONS, FIGHT, INFRA filtered systems)	Detailed analyses of the vessel systems and functions according to the requirements, margins, criteria and constraints.
5	**General Arrangement Phase**		
5.1	Drawing Preparation	Parsing DBB layout (3D) intro traditional 2D GA and lines plan. Detail of DBB into modern 3D GA software	GA, linesplan, 3D rendering

DEVELOPING DBB IN AN OPEN AND COLLABORATIVE WEB-ENVIRONMENT

2D IMPLEMENTATION (2016 / 2019)

Since 2016 an online a simplified 2D design tool inspired by the DBB has been available as a joint collaboration from the first and third author. The first version of the tool was developed at UCL and can be accessed at http://dbb.ucl.im/2016 (Figure 2a, Piperakis and Gaspar, 2016). An extended version was developed by Kramel in 2019 at NTNU, including a more comprehensive resistance analyses as well as closed-form functions for seakeeping (vertical movement, acceleration and roll), observed in Figure 2b (http://dbb.ucl.im, Kramel, 2019). This tool was based on an incipient work from 2015, published last IMDC, attempting to quantifying interfaces in general arrangements (Gaspar and Andrews, 2022).

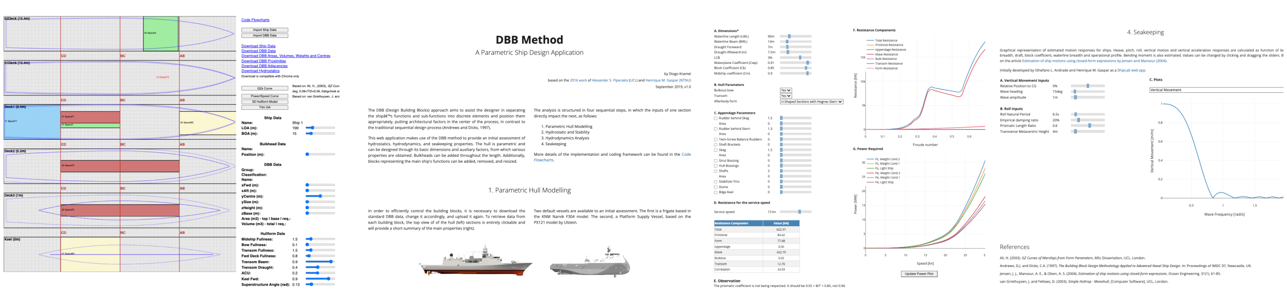


Figure 2 – 2D web-application of DBB by Piperakis and Gaspar (2016) and Kramel (2019)

Kouriampalis et al., (2021) uses this simple (and to be honest not user friendly) prototype DBB design tool to model the operational effects of deploying and retrieving a fleet of uninhabited vehicles (UXVs) in naval surface ships. The design revolves around the innovative idea of a mother vessel capable of transporting and deploying UXVs. The 2016 tool was used to play around with the blocks, allowing the creation, visualisation and manipulation of the ship's GA. After a layout was preliminary established, the numerical sizing was made in Excel, with detail in traditional CASD software (e.g., Paramarine). Figure 3 exemplifies this work, depicting two different internal arrangements made with this simple and 2D ship layout design tool.

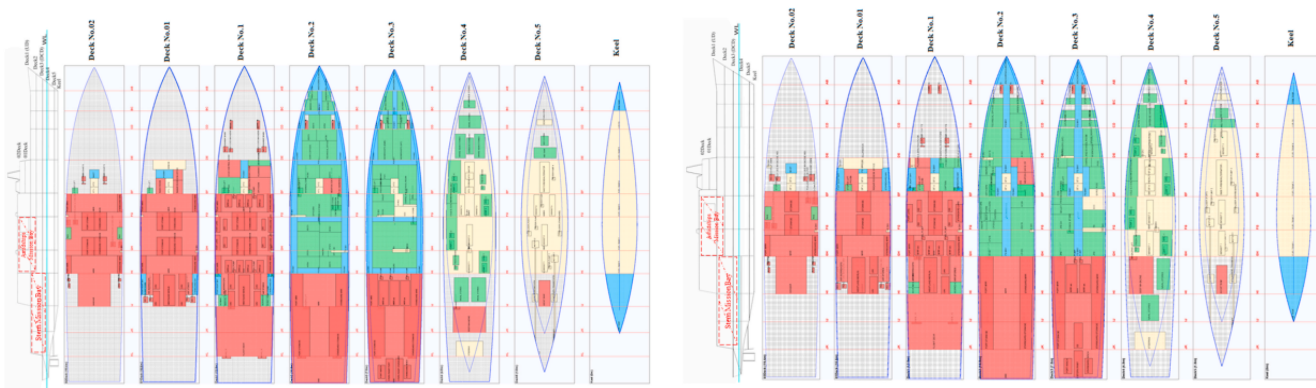


Figure 3 – Internal arrangements for two design variants of motherships made by Kouriampalis *et al.,* (2021), using the 2D web-application of DBB from Piperakis and Gaspar (2016)

3D IMPLEMENTATION – ADAPTING VESSEL.JS: OBJECTS AS BLOCKS

Vessel.js is an open-source library with tools and methods for Early-Stage Ship Design. The library has been described in more detail in previous IMDCs (Gaspar, 2018, 2022). In short, its main characteristics are being developed in JavaScript and employing an object-oriented approach to modelling of digital ship designs. In the same manner as the 2D DBB implementations, the choice for JavaScript stems from its usage in development of web-based applications and user interfaces. This makes it suitable for creation of interactive apps with graphics, such as charts and 3D rendering. All these come in handy when designing a ship, as they provide immediate understanding of architectural implications of a building block, such as its size relative to the other blocks and its interaction with the hull. Other advantages of web applications are their geographic availability with low threshold to use. Users can access apps on any web browsers installed on modern devices without additional installations. This allows students to promptly access developed examples and start playing with them in the classroom. As the source is open, they might eventually inspect the code to understand the logic underlying the analyses, modify it with different functionalities, or reuse it when creating new applications.

Vessel.js' object-orientation means it resorts to the computational concept of an "object" to represent vessel components and even modules used to run design analyses or render 3D visualisations. An object is a variable or data structure which contains values, functions, and methods, usually combined to encapsulate a significant aspect of computation in a single construct. Object-oriented paradigms support inheritance mechanisms, allowing the creation of several object instances, possibly containing different internal values, from a single blueprint, which might be defined as a "class" or "prototype", depending on the implementation. Figure 4 shows Vessel.js' overall structure, containing ship-related objects in blue, design analyses in red, and supporting functionalities in white.

A ship model in Vessel.js comprises a hull, major structural elements, or dividers (decks and bulkheads), and internal systems placed into the ship. Those systems are represented with generic objects, named "base" and "derived" objects. These constructs were created to provide the flexibility when addressing different types of vessel components. A vessel object includes weight and spatial definition about an equipment or compartment, possibly with a 3D model to be loaded in its place (if no 3D model is provided, a bounding box is used instead). A derived object defines a specific placement of a base object, allowing its replication in multiple locations inside the vessel. Base and derived objects are not prescriptive as to whether the element being modelled is a tank, compartment, machinery, equipment, or other component. They simply provide a mechanism to define spatial and weight characteristics and replicate them with a 3D visualisation in the design. These functionalities yield an adequate framework to handle the DBB approach, as a base object might also be created to represent a Super Building Block or smaller Building Blocks, depending on the design stage.

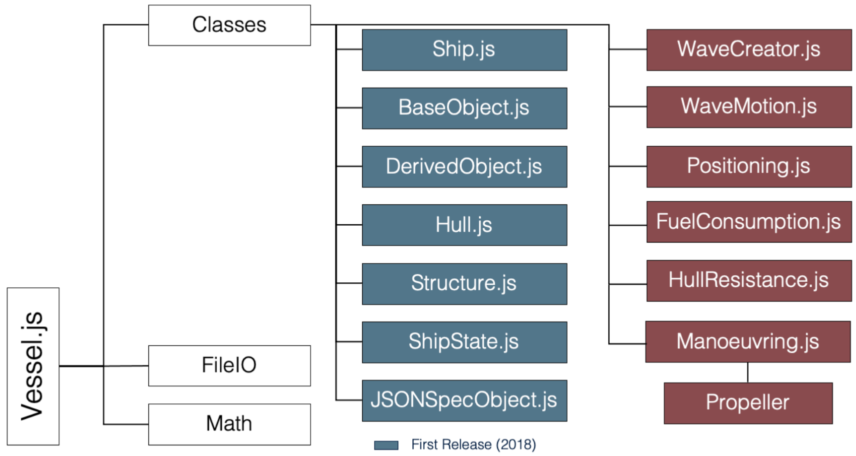


Figure 4 – Vessel.JS structure, with core *classes, fileIO* and *math (Gaspar 2018; 2022).*

In addition, the web-based architecture allows the vessel as blocks to be combined with more realistic descriptions, such as 3D rendered models from gaming and animation. Such models do not incorporate the mathematical modelling but are important to communicate the idea that blocks (early design) and final drawings (with details, colours and texture) are part of the same process. Figure 5 presents cases with both representations. On the left, the blocks, during conceptual design, can be used for the evaluation of the S4 performance, while on the right is the artistic representation, from 3D art and based on sketches. Additional elements like sea or ocean can be added to aid the communication of the final product.

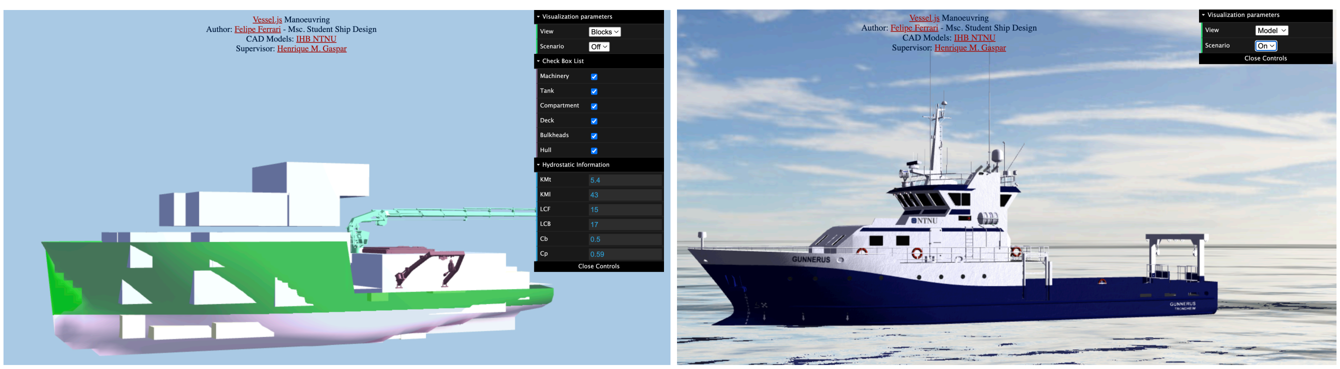


Figure 5 – Vessel.JS architecture blending early design, with blocks and a rough hull (left), used for calculating hydrostatic (right side menu) and the conceptual art in 3D of the same design, with a sea and sky scenario.

A PLATFORM SUPPORT VESSEL (PSV) DBB CASE

Design Preparation, Topside and Major Feature Design Stage

A simplified case study is presented to illustrate the DBB approach using the 3D implementation. The design style was chosen to be that of a modern commercial PSV, an offshore support vessel aimed at transporting supplies between onshore and offshore installations. In that design style, superstructure and engines are placed forward on the vessel, leaving the midship and aft available for carrying cargo, either inside tanks (e.g., for drilling fluids), or on an extensive open deck. Propulsion usually supports Dynamic Positioning (DP) to allow for precise control of the vessel's position in relation to the installation being supplied, which is commonly an oil rig. The design in this case study is inspired by the PX121, a PSV designed and built by Ulstein (Ulstein, 2014).

The taxonomy of building blocks includes the functional group:

- FLOAT: trim and ballast tanks.
- MOVE: propulsion machinery, thrusters and containing spaces, fuel and lube oil tanks, exhaust openings, navigation rooms and equipment.
- FIGHT/OPERATE: cargo decks (open, covered) and tanks.

- INFRASTRUCTURE: accommodation, ship's stores and provisions, auxiliary machinery spaces and systems.

The functional groups are not prescriptive and can be chosen by the designer, to better support their activities. Additional categories such as ACCESS might be adopted in more detailed cases and are suppressed here for simplification.

The design characteristics are situated within a range delimited by a common list of equipment and minimum cargo runs and by mobile temporary storage capacity. Shall and Should requirements elucidation are adapted from the 2015 IMDC case (Gaspar *et al.,* 2015), transformed into feasible combinations. In this exercise, it was decided to constrain the overall size (GT) of the vessel, therefore assuming a new feature (e.g., Ice Class) would mean a smaller capability in another feature of the vessel (e.g., cargo size). Also, not all equipment is compatible, for instance *Towing and Salvage* equipment cannot be installed if a full *Fire-Fighting* capability is necessary, and vice-versa. At the end, Table 2 present the feasible combinations considered during the design preparation phase, with seven missions and five PX121 market options.

Table 2 - Missions, market options and compatibility for PX121

Vessel missions and use	PX121 Mrk1	PX121 Mrk2	PX121 Mrk3	PX121 Mrk4	PX121 Mrk5
Cargo Runs	V	V	V	V	V
Mobile Temporary Storage	V	V	V	V	V
Oil Recovery and Stand by			V	V	
Light Well and Extra Accomodation					V
Towing and Salvage		V	V		
Fire-Fighting				V	
Ice Class	*	*	*	*	*

* - Optional at extra CAPEX

Super Building Block Based Design Stage

The design was first modelled with "Super Blocks", meaning major building blocks, which could have been further decomposed into more detailed Building Blocks. This reduced the threshold to modifying the early-stage design proposal and exploring alternative configurations by reducing the number of blocks to be arranged and provided a higher-level view of space utilisation inside the ship. Figure 6 shows the PSV early design modelled in superblocks. Green superblocks represent INFRASTRUCTURE, yellow superblocks are MOVE, and red superblocks are OPERATE.

Two algorithms for preliminary analyses were selected and applied to the design Constrained Linear Scaling (Figure 7) and Block Configuration Editor (Figure 8)

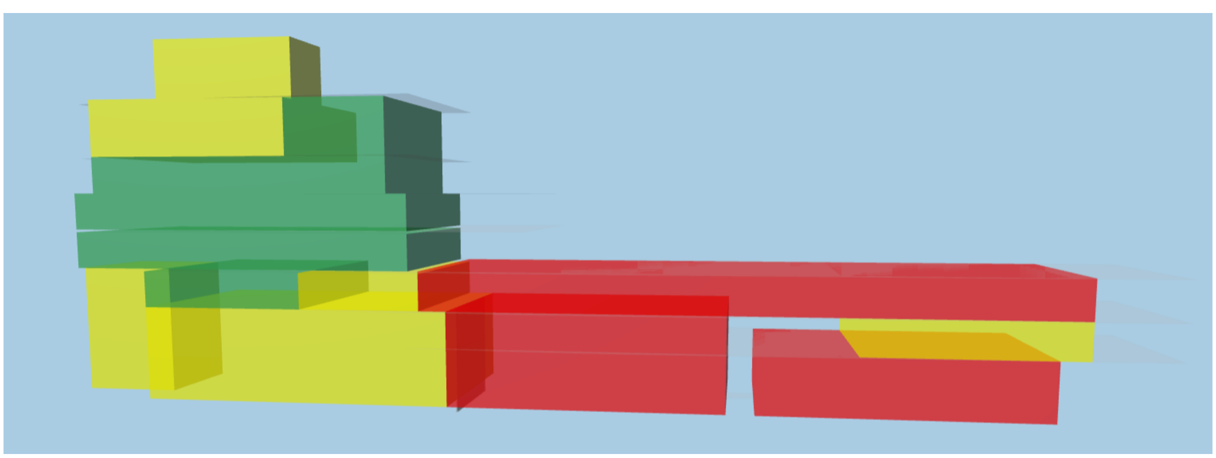


Figure 6 – PSV SBB Representation

Constrained Linear Scaling. The first algorithm allows changing blocks' dimensions while maintaining their sizes and positions in relation to each other constants. The algorithm constrains the total volume of blocks to a fixed number but allows the designer to "stretch" the design's main dimensions: Length, Beam, and Depth. This was developed with a web application where the user can use a slider to scale one of the linear dimensions. Say for instance, that increase Length is investigated, then Beam and Depth will then be automatically adjusted by the algorithm to keep overall volume constant. The user might also decide to lock one of the dimensions to a fixed value, say Depth. This will allow them to resize the Length while the Beam is automatically adjusted to compensate for the modification (and vice-versa). The changes in block and hull sizes are rendered in real time. This algorithm allows quick prototyping of design alternatives with different deck areas and identical volumetric capacities, while keeping an overall arrangement with the same relative positions among blocks.

For example: SBB1 must have 40m3 (criteria x). It can be 2x4x5; 2x2x10. So for each arrangement, L/B/D could be varied, from the smallest L that is acceptable until the largest, seeing real time consequences in B and D. Same with B, and D, with six variations in total, each of them one maximum or minimum, for the same arrangement. One of the dimensions (e.g., L) could be fixed and the others played with (D and B). Each option will then have different tank and deck sizes. If design speed is changed, then the whole design is adapted to it (e.g., larger or smaller propulsion), then the process starts over again.

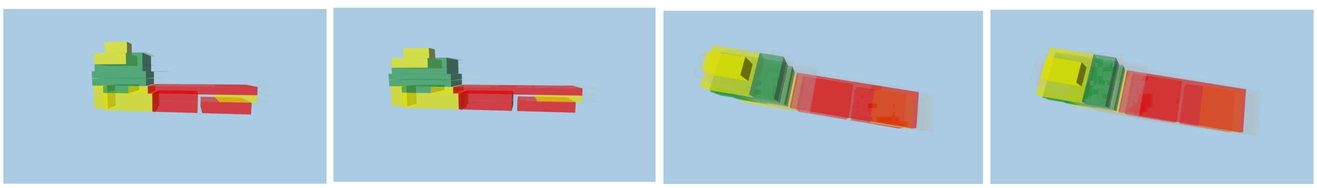


Figure 7 – Variations pf the SBB PSV design by *stretching* and *squeezing* blocks, maintaining the volume SBBs criteria, while *playing* with *LxBxD*

Block Configuration Editor. An alternative algorithm within the DBB approach, involves changing relative placement of the blocks by manipulating them akin to *Lego pieces*. This allows the designer to obtain and evaluate multiple arrangements before further detailing any of such alternatives. Vessel.js' "3D block editor" application allow users to modify design configurations with intuitive manual controls like drag and drop. This expedient can of course be interchanged with the previous one, so that first the designer defines block placement, then adjust dimensions, or vice-versa.

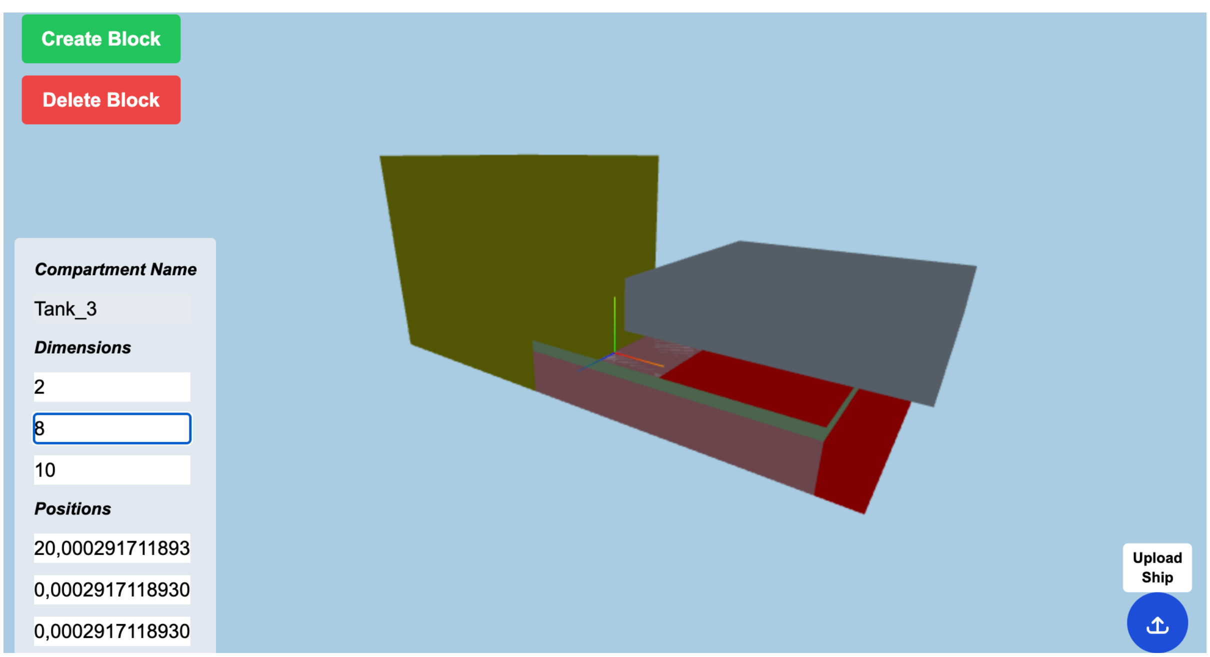


Figure 8 – Preliminary block-editor, able to decompose SBBs into DBBs

Building Block Based Design Stage

Once design balance is reached, the design is refined by decomposing the Super Building Blocks into smaller building blocks corresponding to the position of specific vessel systems. Figure 9 illustrates the PSV design after being refined with 106 building blocks. Similar *stretching* and *squeezing* was performed, to test 441 different variations of the design according to the criteria.

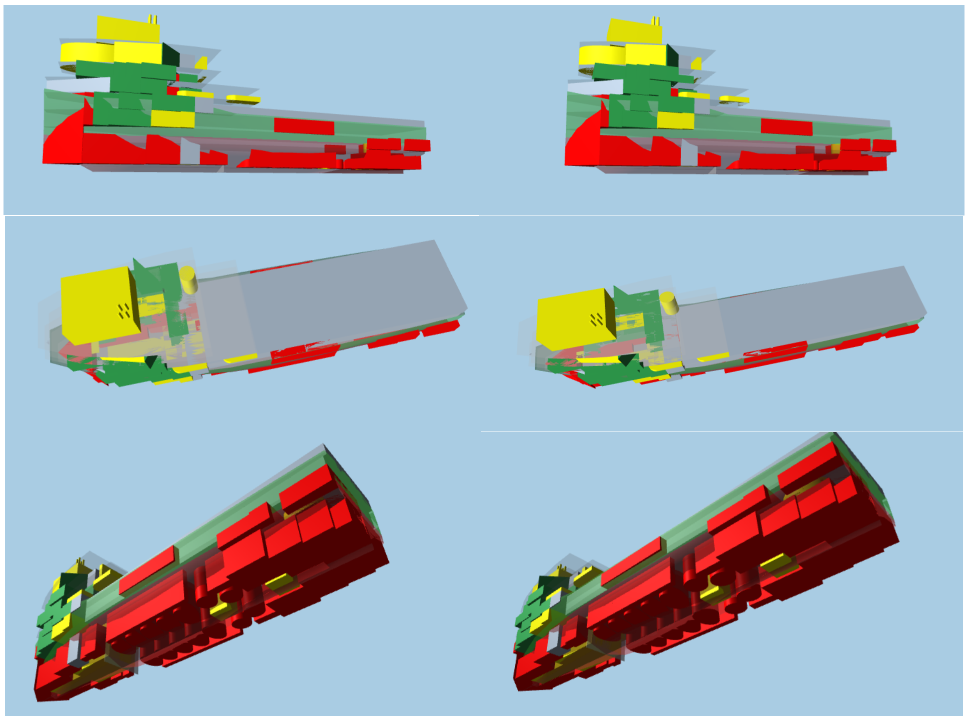


Figure 9 – 441 solutions were developed, with 106 DBBs, maintaining the fixed GT constraint.

At this stage, a more refined evaluation of design weight, hydrostatics and stability balance is carried. An existing Vessel.js app receives the digital ship definition in JSON format and plots a report containing the list of blocks, with positions and weights, and a summary of hydrostatic parameters for that design (Figure 10).

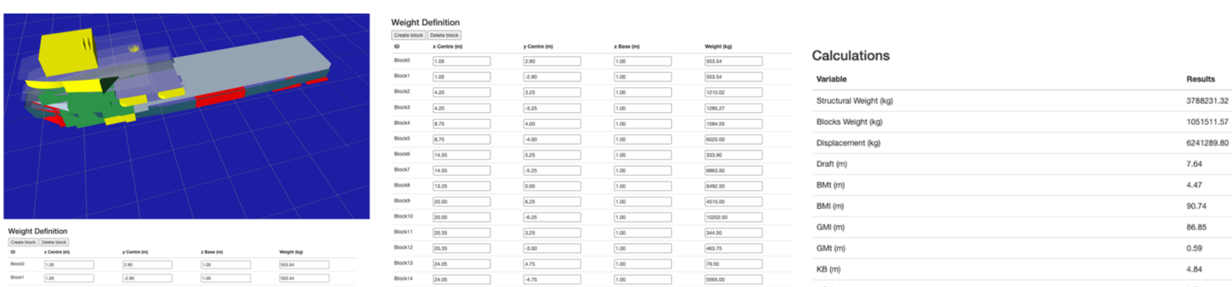


Figure 10 – PSV DBB hydrostatic data using vessel.js library.

General Arrangement Stage

Resorting to a combination of a 3D-first design approach and tools allows a simple General Arrangement to be automatically generated as a by-product of the 3D visualisation created during the previous steps, instead of having it being drawn manually as a separate document. A specific Vessel.js web app renders top views of the ship model on each deck, resulting in the General Arrangement depicted in Figure 11 As the PSV design was detailed, building blocks were gradually substituted by 3D models of parts and equipment. The GA was consequently updated toward a detailed version adequate to upcoming design stages.

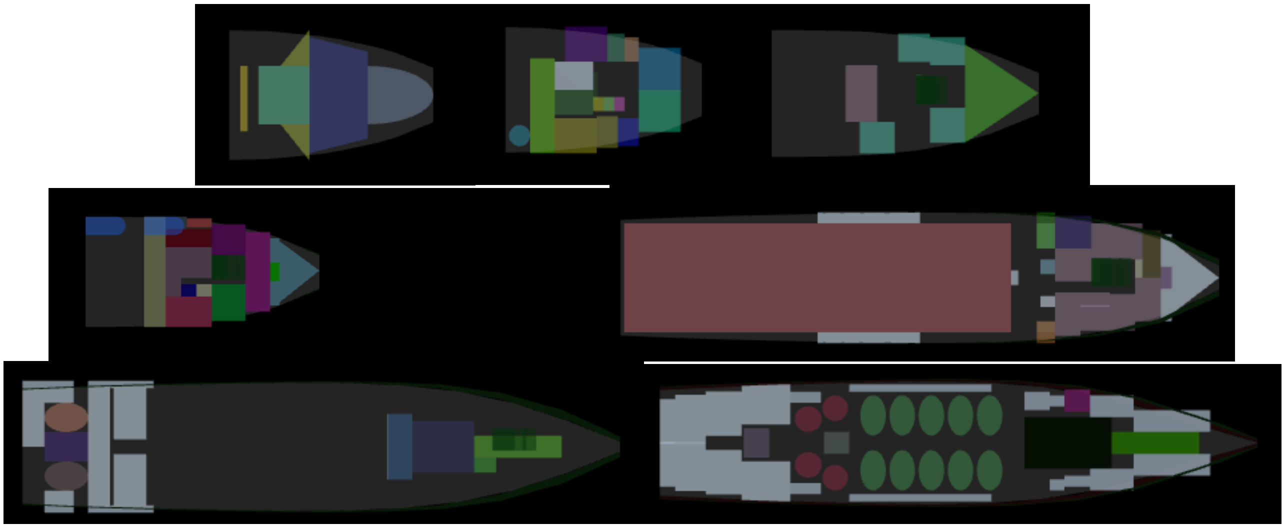


Figure 11 – Simple GA from blocks, adjusting the camera from the web-based render.

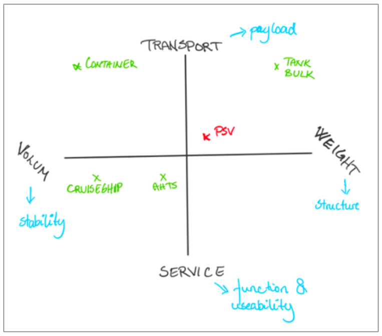
DBB USE IN BSc STUDIES – INNOVATION IN THE SPECTRUM OF SHIP DESIGN METHODS

Since 2017 the second author has attempted to introduced DBB method in his *SKID2300 Ship Design III - Design Methods* in combination with other methods, in his NTNU modules (Gaspar, 2023). The course is offered in the 5th semester of the BSc in Naval Architecture (Ship Design Course), in Ålesund, Norway. The students at that stage have already learnt the fundamentals of S4 (Andrews, 2018), so they are sure that they can calculate stability, resistance, design a safe hull, comply with regulations and classification, and understanding a (basic) dynamic response of the vessel (seakeeping / dynamic stability). It is one of the objectives of this last course, thus, to present to the students a compilation of more modern and realistic ship design methods. This is given theoretically by the second author, and in practice, by Øyvind Kamsvåg, Head of Design at Ulstein Group (Kamsvåg, 2018). Importantly, this course was designed with the intention of rekindling the students' desire to be creative, that the two previous years of analyses had supressed. The logic of the course is the following:

1) Self-evaluation from the previous design exercises: The student has to explain their previous designs, and is challenged with critical thinking questions, specially connected to *Why X and not Y*. It is no surprise that the usual answer *is because I copied from Z, and they used it*. It is also in this phase that the student realise that their previous attempts are addressing the learning of an analytical skill (e.g. *stability or resistance*) rather than designing skills.

2) Mission Matrix and Requirements Elucidation: This phase presents two basics taxonomies to the students. First, that vessels operate in a spectrum of *Service and Transport*, and that they can be designed to maximise *Weight or Volume*. This is a starting point to point to expose the limitations of the basic design spiral, as well as that their previous attempts, which addressed analytic skills, can now reveal that to produce a new design requires a stylistic choice on their part (Andrews, 2018). In other words, it's a stylistic decision from the designer to place the design more towards one or other side of this *spectrum*. Requirements Elucidation are tackled with the Shall / Should approach, and so communicate expectations. Figure 12 presents a collage from student's reports: in the left the *Mission Matrix* and in the right *a Shall / Should* example for a PSV.

3) Top-Down Methods (Reference Ship / Catalogue / StO): Top-Down is here used to describe ship design methods that have a starting point data from formulas, regressions, previous designs and parametric studies based on existing solutions, such as the one commented in Parsons (2011), most of Watson and Gilfillan (1976) and Roh and Lee (2018). Such top-down approaches to collecting data, usually find a practical and consensual solution in a short time and cost but lacks innovation and carries on the bias and out of date insights from previous designs. At this step is important to go into the detail of the design of a reference ship, understanding the design and stylistic choices that the designer of that ship has made. In this stage the Systems Based Ship Design (SBSD) Taxonomy from Levander (2006) is also introduced, asking as a core exercise that the student decompose the ship into a functional breakdown, such as *Ship Systems* and *Payload Systems*.



a)

Requirements	Shall	Should
Payload		
Baseoil, m^3	200	250
Drill water, m^3	1000	1500
Brine, m^3	800	1000
Methanol, m^3	150	250
Mud, m^3	1000	1500
Deck capacity, *tons*	2750	3000
Dry bulk, m^3	250	400
Fresh water, m^3	1000	1250

Performance		
Economical speed, *knts*	10	12
Max speed, *knts*	14	15
Accomodation		
Crewspace	25	25
Dimensions		
T, m	6	7
D, m	7.5	8.5
LOA, m	85	90
B, m	20	20

b)

Figure 12 – a) Mission Domain Matrix (*Service x Transport / Volume x Weight*); b) *Shall / Should* description of requirements

4) Bottom-Up (Design Inside Out, SBSD++, proto-DBB): Bottom-up methods are here understood as starting the design from specific key elements and subsystems that directly affect the mission of the ship. Bottom-up data presents different taxonomies or different vessel descriptions and understanding them, such as in SBSD and DBB. Bottom-up data is the starting point for innovative and technological break-through designs, but may suffer from the lack of knowledge connected to the uncertainty of one-of-a-kind projects. A key change to the traditional SBSD method, is to introduce the concept of DBBs, with the addition of distinct colours to identify the functional breakdown. Figure 13 presents this exercise made for a RoPax Ferry (left, in Norwegian) and a Factory stern trawler (right).

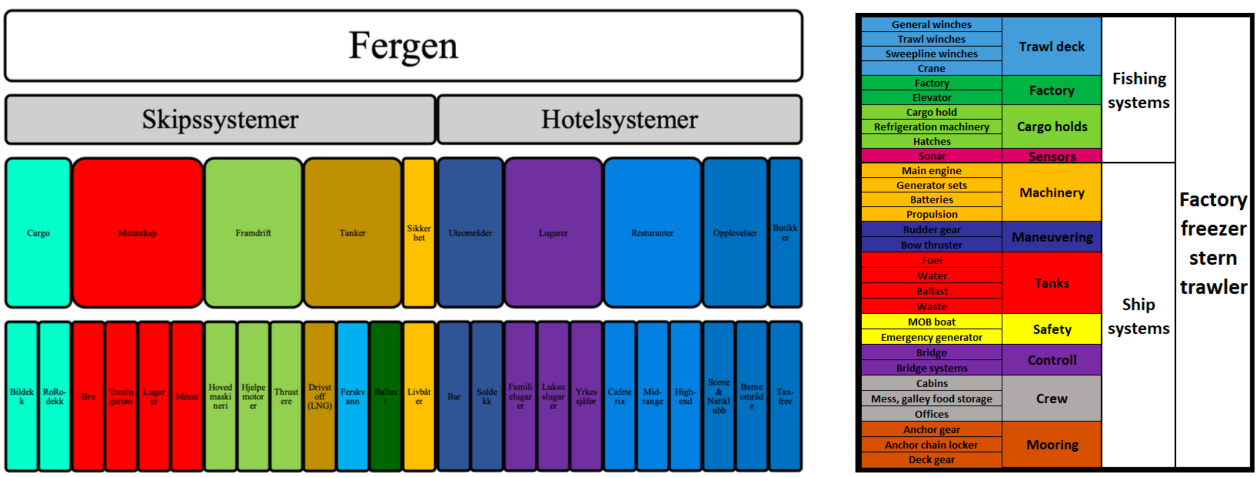


Figure 13 – From functionalities break-down to colours - initial step to connect SBSD and DBB

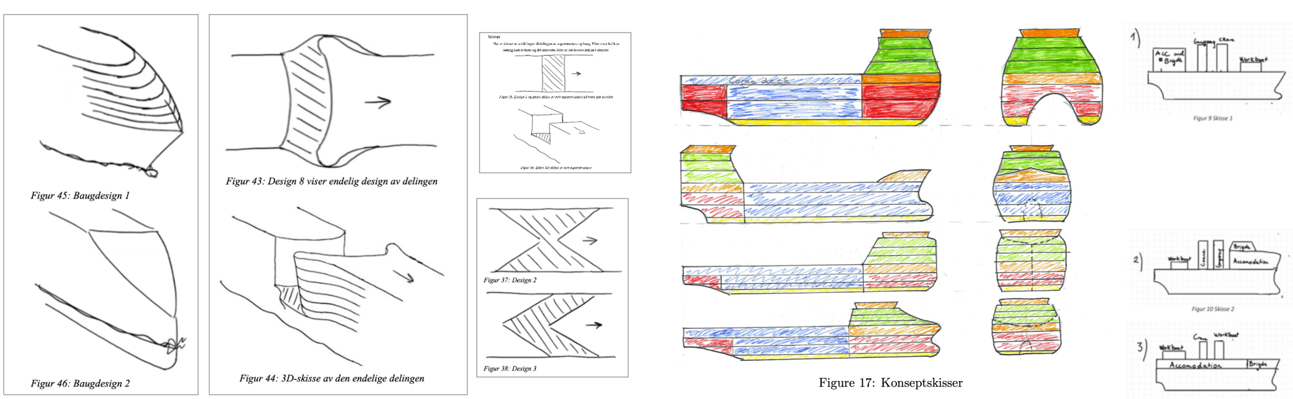


Figure 14 – Sketches to foster innovative solution in BSc student designs.

5) Sketching and design space exploration: This step is crucial, as the students have a class in the middle of the course to pause the dense theoretical approach and sketch, freehand, the innovative and key elements that are the core of its mission. Is it emphasised that artistic qualities are not being judged, but this is rather an exercise to explore solutions out of the box. Figure 14 presents a collage of sketches from the students.

6) Proto-DBB Exercise: This stage gets the students to implement some of the DBBs methods to explore their innovative ideas. The functional breakdown from Step 3 is used to create a simple library of SBBs, mostly visual, that is, not necessarily provided in ship design software. The core of this phases is not the comprehensive validation of a concept, but the use of 2D and 3D tools to *play around* with the newly sketched ideas. That said, the *weapon of choice* is for the student to select. Some use traditional naval architecture software, like Maxsurf (Passenger Ferry Design, Figure 15a), others use drawing tools like AutoCad or Sketch-Up (Cruise Ship, Figure 15b). The important thing is for them to explore the design space.

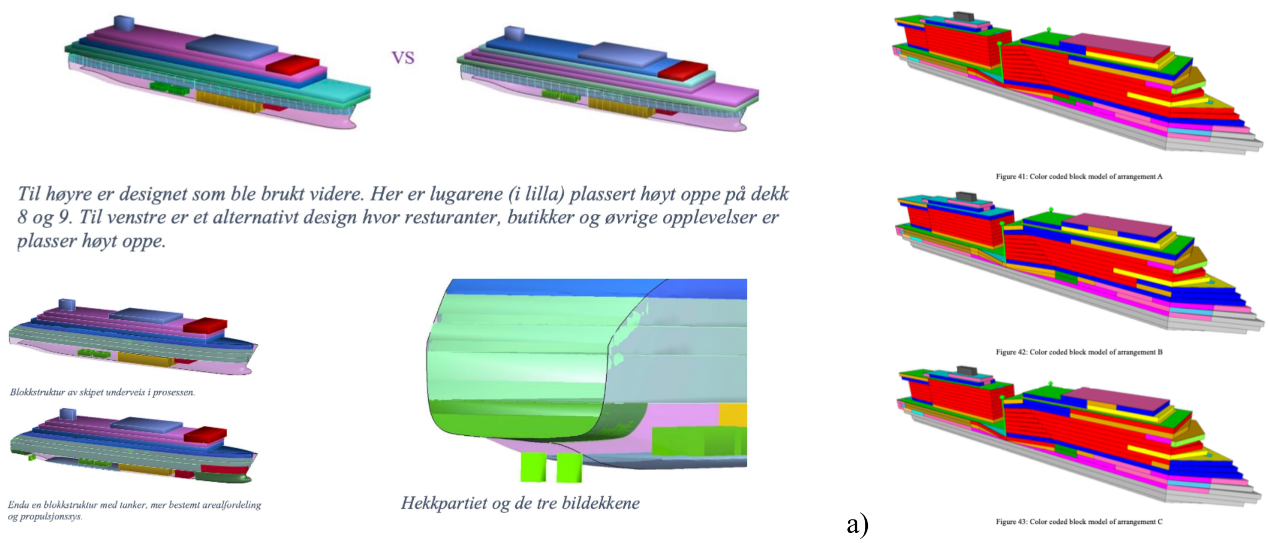


Figure 15 – proto-DBB exploration of a passenger Ferry (a) and Cruise Ship (b)

7) Tabular Summary and GA: Parsing the blocks and assembly into useful information is the next step. The student thus converts the blocks into volumes, areas, weights and centres, in a way to quickly input the data in the existing S[4] tools. A GA is also created, documenting the innovative design in the proper manner. Figure 16 exemplifies this step.

Kategori	Vekt [t/m2]	KG [m]			Areal [m²]			Volum [m³]			Vekt [t]		
		A	B	C	A	B	C	A	B	C	A	B	C
Passasjer accommodation	0,250	32,50	31,00	32,00	51379,00	37070,00	46862,00	154137,00	111210,00	140586,00	12844,75	9267,50	11715,50
Servering	0,250	29,50	28,00	29,50	8573,00	14269,00	10211,00	25014,00	42102,00	29928,00	2143,25	3567,25	2552,75
Spa og Fitness	0,250	37,00	37,50	37,00	2837,00	3517,00	2837,00	6555,00	8595,00	6555,00	709,25	879,25	709,25
Dekksaktiviteter	0,250	41,50	40,00	41,50	7009,00	5084,00	7009,00				1752,25	1271,00	1752,25
Underholdning	0,250	14,50	16,00	14,50	2360,00	3508,00	2360,00	7080,00	10524,00	7080,00	590,00	877,00	590,00
Vannaktiviteter	1,000	32,50	35,50	32,50	2858,00	4783,00	2858,00	3105,00	3105,00	3105,00	2858,00	4783,00	2858,00
Innendørs aktiviteter	0,250	31,00	33,00	32,50	10785,00	17450,00	13643,00	32355,00	52350,00	40929,00	2696,25	4362,50	3410,75
Servicefasiliteter	0,250	29,50	29,50	27,50	1342,00	960,00	1237,00	4026,00	2880,00	3711,00	335,50	240,00	309,25
Mannskapsfasiliteter	0,250	11,50	11,50	11,50	8995,00	8995,00	8995,00	26985,00	26985,00	26985,00	2248,75	2248,75	2248,75
Innvendige rom	0,300	8,50	8,50	8,50	20355,00	20857,00	20481,00	58984,00	60490,00	59362,00	6106,50	6257,10	6144,30
Kontrollsystemer	0,900	23,50	23,50	23,50	545,00	545,00	545,00	1659,00	1659,00	1659,00	490,50	490,50	490,50
Redningsutstyr	6,000	14,50	14,50	14,50	1600,00	1600,00	1600,00				9600,00	9600,00	9600,00
	[t/m³]												
Maskineri	1,000	5,00	5,00	5,00	6069,00	6069,00	6069,00	21037,00	21037,00	21037,00	21037,00	21037,00	21037,00
Tanker	1,000	3,00	3,00	3,00	17382,00	17382,00	17382,00	41344,50	41344,50	41344,50	41344,50	41344,50	41344,50
	[t]												
Manøvreringssystem	500,00 20,00	5,00	5,00	5,00	2089,00	2089,00	2089,00	6651,00	6651,00	6651,00	520,00	520,00	520,00
Fortøyningssystemer	25,00 5,00	13,00	13,00	13,00	950,00	950,00	950,00	2850,00	2850,00	2850,00	30,00	30,00	30,00

Figur 60: Tabell 2 viser dataen og utregningen til cruiseskipet a)

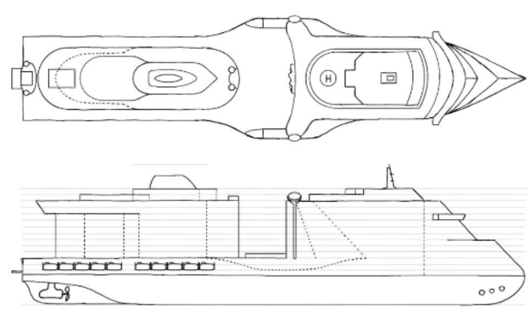

b)

Figure 16 – Tabular conversion of blocks into weight, centres, volumes and areas (a) and final design drawings (b)

WITHER NOW THE DBB: ADVANTAGES, LIMITATIONS AND PROMISES WHEN BORDERS ARE EXTENDED

The first two authors share similar experiences from the ship design approach taught during their graduation years. It was aimed at vessels for commodity transports and relied on methods heavily reliant on previous designs, such as use of regressions and of previous general arrangements for vessels of comparable size and capacity. From the commercial perspective, this might be a suitable combination for transport vessels as they are often designed to similar (if not identical) requirements and might as well be standardised for reproducible manufacturing in shipyards. From the educational perspective, it might be useful to have students have their first design experience with that a non-original set ups for two good reasons. First, it gives them some confidence that their design decisions are at least plausible, by providing external references. Second, it provides them with the opportunity to practice basic design analyses (e.g., stability assessment, propulsion sizing, structural dimensioning) in an exercise environment where the solution is roughly known beforehand. This means propulsion will be comparable to that of other Suezmax vessels and so will adopt the same compartmentation and similar aspects.

The disadvantage of such regression-based methods is that once students and practitioners are familiar with the knowledge needed for addressing common design aspects, the process tends to become mechanistic and repetitive, as a direct consequence of design reuse. In that sense, the DBB approach puts higher emphasis on holistic and architectural design concerns. It assumes the ship designer already has sound knowledge (and maybe even intuition) of fundamental trade-offs incurred by key design decisions and, for that reason, is able to focus on space use and arrangement without losing sight of the ship as a whole system. As already pointed, this gives the designer greater autonomy to explore design alternatives (and thus innovate) by not resorting to prescribed templates. It also reduces the threshold to iteration in early design by giving a set of elements (building blocks) that can be directly manipulated to consider and evaluate different alternatives without committing to any in detail. As a result, it can be said that the overall process becomes more engaging as it gives the naval architect space to explore the design problem with a creative mindset, instead of being limited to being the professional who ensures a previously chosen design sticks (without questioning) to applicable rules and standards by class, IMO, or others.

The attempts to extend the boundaries of the DBB discussed here are far from finalised, and many shortcuts were taken. The 2D and 3D online tools are in an incipient stage of development, given the lack of commercial support. The example from the BSc course is limited by the scope of the course, as well as the strong connection that the campus from NTNU in Ålesund has with the local ship design companies. In this sense, elements from DBB are adapted and merged with other methods. It is important to reiterate, however, that the proto-DBB exercise is one of the highlights of the course, resulting in engaged and motivated students. We invite the readers, naval architects working for the industry or academia, to dig into the references and adapt for their cases, DBB elements, especially if the aim is to explore innovative designs.

Given that, before the research and teaching at NTNU described in the latter part of this paper, the only research and educational use of the UCL Design Building Block approach to synthesising complete descriptions of ESSD were those in the Design Research Group team under the third author at UCL, it is worth ending this *Whither* paper by considering whether the DBB approach in an age of "advanced CASD", with AI and ML implications, can be adopted more widely. This needs to be considered from both a teaching/academic research perspective and actual ESSD "in the real world". It is the case that the specific Paramarine applications of the UCL DBB approach (facilitated by the SURFCON module incorporated in the Paramarine suite (Monez and Forrest, 2002)) have been used "for real ship design" by ship design agencies, including non-naval ship designers (www.paramarine.qinetiq.com).

It is hoped this academic and wider usage will be undertaken in a manner consistent with the intent that the current paper's introductory remarks re-iterated. As part of considering how this might be taken forward the following remarks are offered:

- There are clear different types of ship design approaches due to its very diverse nature. Andrews (2018) spelt this out in Table 3 and Section 5, covering the range of design novelty undertaken with specific extra sections: Sections 8.1 (configurationally driven designs); 8.2 & 8.3 (examples of unconventional hullforms) and "the very special case of submarine design (Section 8.4). All of the latter can only be sensibly synthesised by a DBB like architectural approach, while the conventional monohull also ought (especially if "novel" to any noticeable degree) to be designed "inside-out" (i.e., a DBB like approach).
- Accepting a requirements elucidation approach (see Section 3 of Andrews, 2018) even the conventional monohulled service vessel when synthesised "inside-out", can (and normally should) be explored for different

internal configurations to see what is "best" as part of requirements elucidation. (A quite old but very comprehensive presentation of different configurations explored as part of the design of a major new class of combatant was provided by Leopold and Reuter (1971) - see Figure 7.) The message of a DBB type approach is that different internal configurations can be readily explored and tied to the numerical balance (through the Paramarine NA suite) so that the whole outer hull (and the superstructure) can be readily adjusted to accommodate "better" internal (DBB) configurations. This is creative ship design.

- A final set of SD educational remarks: Teaching ship design, both progressively to undergrads and to more general engineering graduate entrants (at NA masters level) can be done in steps and using an architectural/sketching approach (see Pawling and Andrews, 2011); the higher level of PhD and post-doctoral SD research is best fostered by a DBB type approach (see Andrews (2018) Sections 6.2 and 6.3 for UCL examples of new ship designs and researching specific ship design issues for whole ship implications); Sketching needs to be fostered as part of inside-out/architectural/DBB exploitation – to both encourage creativity and to not be limited by specific tools. This further encourages innovation and the necessary dialogue with design stakeholders (especially requirements owners/operators/funding bodies).

CONTRIBUTION STATEMENT

All Authors Equally: Conceptualization; data curation, methodology; writing.

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