Application of Templates to Early-Stage Ship Design

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Abstract— **Current efforts to bring design of distribution systems earlier in the ship design process will advance the Navy's abilities to assess the impact of ship systems on overall ship performance. System design in the early stages of ship design is currently a labor-intensive manual process. Streamlining and automating system design will enable incorporating the capability into exploration of broad trade spaces such as accomplished using the Navy's Rapid Ship Design Environment (RSDE). The work presented herein produces distributed system designs in a semi-automated manner appropriate for eventual inclusion in RSDE, based on a small amount of input provided in template format.**

Keywords—early-stage ship design, ship distribution system design, design-space exploration

I. Introduction and Motivation

The Navy currently employs a suite of early-stage design tools consisting of an overarching design space exploration tool (the Rapid Ship Design Environment or RSDE [1]) running a number of modular programs that perform design and analysis functions for different aspects of the ship design. All of these programs persist design data in the Leading Edge Architecture for Prototyping Systems (LEAPS) data repository [2] using a product meta-model that defines the storage of surface ship data, titled the Formal Object Classification for Understanding Ships (FOCUS) [3]. The current design tools produce a hullform using the Hull Form Transformation Utility (HFT) to support synthesized ship design using the Advanced Ship and Submarine Evaluation Tool (ASSET), then evaluate resistance and seakeeping performance using Ship Hullform Characteristics Program - LEAPS (SHCP-L) and Integrated Hydro Design Environment (IHDE). The current tools do not include a system modeling and analysis tool that details the components and provides synthesis capability.

The Office of Naval Research has tasked the Electric Ship Research and Development Consortium (ESRDC) to develop a ship system design environment; the resulting Smart Ship System Design (S3D) is in the process of being converted to be LEAPS- and FOCUS-compatible for adoption by the Navy ship design community. In addition, development of S3D continues in order to expand capability. The current manifestation of S3D significantly enhances the state of the art for simulation capability in the early stages of ship design; within S3D, a fully-connected shipboard distribution system can be created by selecting components from an equipment library, connecting them logically in a one-line-diagram view, placing them in three-dimensional space in a ship model, and running load-flow-level simulations on electrical, thermal and mechanical views of the systems, for both individual alignments and more complex mission scenarios. This capability may be used to create new systems from scratch or to flesh out rudimentary distribution systems created in other design programs such as ASSET. However, at the current time, this process demands a person-in-the-loop; the creation of such systems is a manual process.

In order to incorporate the system design and analysis capability into the design-space exploration paradigm of the Navy's early-stage design process, a methodology for automation of system design is needed. One possibility for such automation is a pattern and templating process, in which systems or portions of systems are pre-designed then modified as required and applied to a specific ship design.

II. Templates and Patterns

Patterns and Templates are concepts for reducing the labor required in designing systems by copying and adapting pre-designed and pre-validated portions of systems to specific ship designs. We provide a quick introduction to Patterns and Templates below; the concepts were introduced in [4] and the current status is discussed in [5].

A Pattern is a high-level view of a system or portion of a system, consisting of a connected set of functional blocks plus general design rules and guidelines for creating a system. A Template is an aggregated set of components that are fully connected and parameterized and that make up a portion of a ship system or even an entire ship system; thus, a Template is a more fleshed-out version of a Pattern that has been applied to a specific design scenario or application, but not yet applied to a specific vessel.

As an example, Figure 1 portrays a pattern with four functionality blocks that generate, convert, transfer and use power – shown as a power generation module (PGM), power conversion module (PCM), power distribution module (PDM) and Load. The corresponding template replaces the general functionality blocks with specific components: gas-turbine

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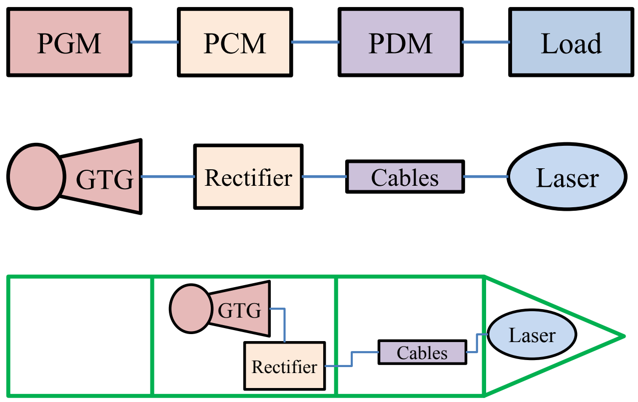

Figure 1. Example Pattern (top), Template (middle), and Template instantiated in a ship design (bottom).

generator, rectifier, bundle of single-conductor cables, and laser weapon. The specific components in the template use the same logical connectivity as the general functionality blocks in the Pattern. When the Template is applied to the specific ship design, the components are assigned physical locations and orientations, the cable lengths and routing paths are defined, and the system rated voltage and current are specified.

The thinking on Templates and Patterns is still evolving. Whereas the basic definition has begun to solidify, the exact level of definition at each stage of the process is still under discussion, and the methodology for employing Templates and Patterns in early-stage ship design is still quite fluid. Several ideas have been postulated; for example, Templates could constitute fully designed systems for an entire ship, fully designed sections of ships such as zones that are assembled and connected at the interface, or small segments of systems that are assembled to create a fully designed system. The work described herein explores this third methodology for the application of Templates, building on [6]. For the remainder of the paper, we use the terms templates and template segments (in lower case) to describe logically connected sets of components that represent a portion of a distribution system, similar to the Navy-defined Templates.

III. Design Methodology

We propose a methodology for creating a distribution system to move a commodity from a set of sources to a set of sinks, assuming that the sources and sinks are known at the outset of the process. This process is applicable to a wide range of distribution systems such as electrical, cooling water, firemain, and data. For ease of discussion we define a clear problem statement as follows: we will create an electrical distribution system that moves electrical power from generators to individual components that consume or store power. The generators and loads are assumed to be known, with the following data established: the amount, voltage and frequency of power generated or consumed; and the location, orientation and size of each generator or load component. The software automatically creates a distribution system to transfer, convert, control and isolate the power flow based on the templates designed and selected by the user. Thus, the distribution system functionality and design is integral to the templates and not hard-coded into the software.

A key feature of the proposed methodology is flexibility. This is not a pre-designed system that must be manually reconfigured for each change in either generation or consumption functionality in the ship design, or for changes in the number of zones or the dimensions of the vessel. For the given problem statement, a fully pre-designed system would contain a set number of connections to generators and loads, and a set number of zonal divisions. If any change were made to the given data (such as the number or location of generators, the number or location of loads or the number of zones in the vessel) a separate template for each variation would have to be created. Instead, the methodology defined herein applies the same template to each of these variations. The templates only need to be altered for changes in the actual distribution system; for example, a single bus versus a dual-bus, or dc main bus distribution versus ac main bus distribution.

IV. Software Overview

The goal of the work described herein is to develop a semi-automated design methodology and tool that can be applied to any distributed system such as electrical power, chilled water, seawater, firemain, data, or communications. This methodology, titled the "System Builder", provides a distributed system design that connects sources to sinks based on rules defined by templates chosen by the designer.

The System Builder code is written in C++ and operates on a LEAPS database using the LEAPS application programming interface (API), and data is stored in a FOCUS-compliant manner. Thus, the results of the System Builder are available to any other LEAPS-integrated software for further analysis such as weight evaluation, hydrodynamic and stability analysis, system simulation, or survivability analysis to name a few. Since this is a system arrangement tool, linkage to the Smart Ship System Design (S3D) environment is especially important.

We begin with a synthesized ship design created in ASSET and stored in a LEAPS database. This ship design provides a hullform and superstructure with decks, watertight bulkheads, and zones defined. Also included are individual components defining the major machinery items such as engines, generators, and propulsion motors. Major payload items are currently defined in ASSET through a spreadsheet-style input; future versions of ASSET may represent these items as individual components. Until that time, individual components for payload items and components representing aggregated loads that are not individually modeled must be added to the LEAPS database through another methodology; this can currently be accomplished using S3D.

A second database is populated with system template segments containing portions of the distribution system of choice; these template segments can be created using S3D and are described further in Section V below. The System Builder assembles user-selected template segments into an electrical power corridor or backbone which collects power from onboard generators and distributes power to all loads. Relevant components are placed in 3D space in the proper zone and logically connected, and the associated S3D simulation models are linked as well. The resulting system is stored within the ship design concept in the LEAPS database. Each of these steps is described in more detail below, along with the current status of the software.

V. Template Creation and Structure

The distribution system is created by assembling a main distribution backbone (e.g. a ring-bus or a dual-bus), then connecting the sources and the sinks to this backbone.

By varying the templates chosen, the program can create quite different distribution systems. As an example, see Figures 2 through 5. Figure 2 displays a baseline set of major equipment placed in a six-zone vessel, including power generation modules (PGMs) consisting of a gas-turbine generator and appropriate converter, propulsion motor modules (PMMs) consisting of the propulsion motor and motor drive, and one generic aggregated load per zone. Figure 3 displays this equipment connected in a ring-bus configuration: each PGM is connected both port and starboard, each PMM is singly connected to the ring bus at the closest point, and each aggregate load is fed by two redundant power conversion modules (PCMs) per zone. This configuration is switchboard-less, assuming that the power electronics control the flow of power. Figure 4 displays the same baseline equipment connected in a dual-bus configuration with one or two power distribution modules (PDMs) per zone as needed; these PDMs represent bus nodes or switchboards. In this configuration, each PGM and each PMM is connected both port and starboard at the closest PDM, but each aggregated load is supplied through a single PCM fed from either the port or starboard bus, alternating by zone. Power source redundancy is provided through a cross connect to an adjacent zone. Figure 5 displays the baseline equipment in a single-bus configuration with one PDM per zone providing connectivity to the PMMs, PGMs and loads.

As stated earlier, the logical arrangement for each of these distribution systems was created using the same underlying algorithm but different template segments. The algorithm proceeds as follows:

- Select the appropriate template segments for the power corridor backbone and the arrangement sequence. Figure 3 uses three template segments in an A-B-B-B-C sequence, Figure 4 uses two template segments in an A-B-A-B sequence, and Figure 5 uses a single template segment in an A-A-A-A sequence.

- Copy the segments to the appropriate ship zone and connect them to one another.

- Select appropriate template segments to use for connecting sources and loads to the power corridor backbone. Figures 3, 4 and 5 all use one template for the PGMs, another template for the PMMs, and a third template for the aggregated loads, although the specific template chosen is different for the different distribution systems.

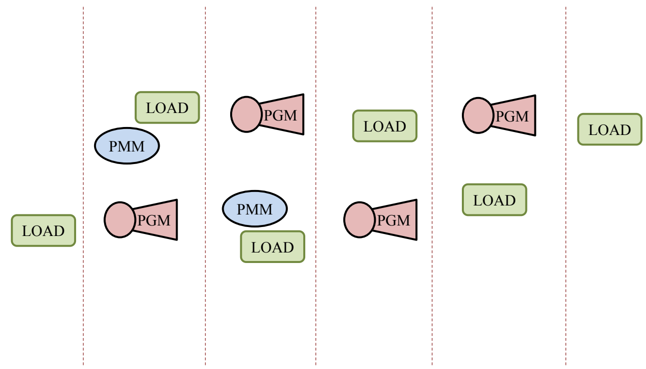

Figure 2. Baseline equipment

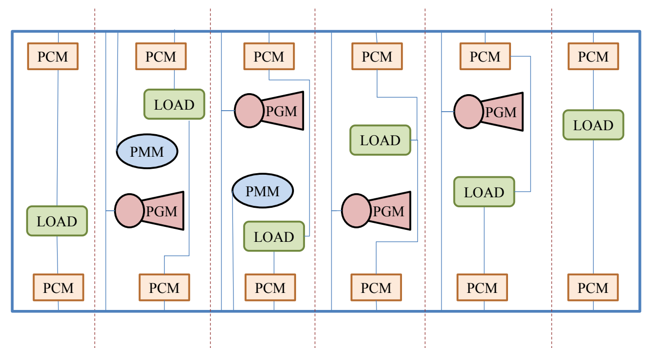

Figure 3. Ring-bus distribution system.

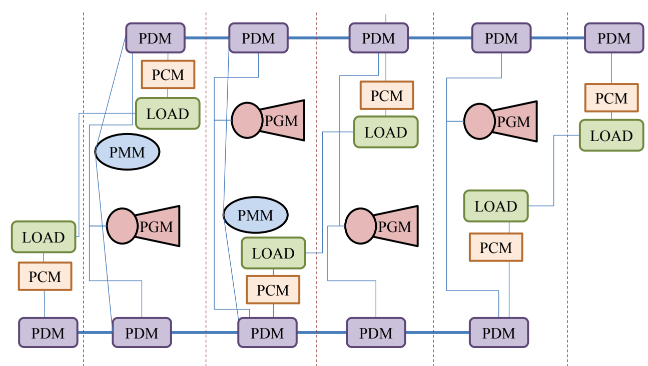

Figure 4. Dual-bus distribution system.

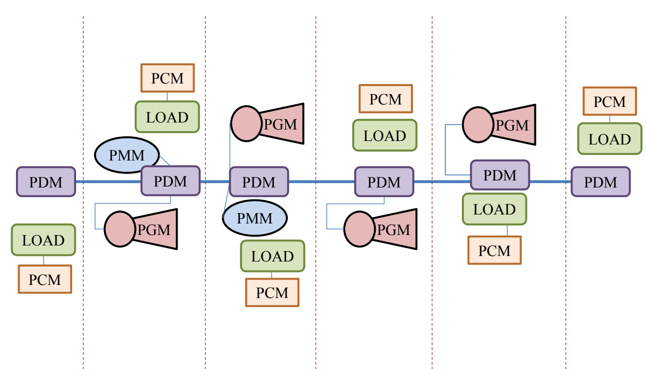

Figure 5. Single-bus distribution system.

- For each PMM, PGM and load in the ship model, copy the template segments to the appropriate zone and connect them to the indicated components and the power corridor backbone.

Each template segment consists of all the components required to fully define the power distribution system in the section under consideration, properly connected. The template segments can be created in S3D and stored in a LEAPS database. Since the complexity of the system exists within the templates and not in the connectivity process, this methodology is applicable to essentially any type of system backbone.

VI. System Assembly

The methodology for linking template segments into a cohesive whole was developed and implemented as follows.

A. Power Corridor Backbone Assembly

Since the power corridor backbone is assembled in sections, there must be provision to ensure each connection from one segment to another is connected to the proper components in each segment. While it may be obvious to a person assembling the system which connection should be made, there must be a method to ensure that systems are properly connected in the envisioned automatic mode to avoid such things as the port bus being connected to the starboard bus at the zonal junction, or the forward end of the starboard bus being connected to the aft end of the starboard bus within the same zone, creating an islanded loop instead of a connection forward and aft.

To ensure proper connections, each power backbone template segment is constructed to include temporary components, denoted "plugs," which are used to connect to the next segment. When the bus is assembled, the plugs are removed and the system connectivity elements (nodes and linkages) associated with them are connected to the adjacent template segment, as shown graphically in Figure 6.

Figure 7 shows the results of applying the same forward, midship and aft template segments to a three-zone vessel (top) and a four-zone vessel (bottom). In the three-zone vessel, there is a single instance of the forward template, midship template, and aft template applied and connected in that order. In the four-zone vessel, the midship template is applied twice (once for each of the internal zones).

As an aside, one of the possible templating methodologies under discussion is to have fully designed zones that are assembled in order. The plugging methodology described in this section would accomplish this.

B. Connecting Sources and Sinks

Since the number of sources and loads in each zone is not known in advance and the connecting paradigm, e.g. whether a component is connected both port and starboard or only to one side, is also unknown, we do not pre-suppose a number of plugs for creating the connections. Instead, we create a proxy blank component representative of the component to which we connect. For example, when connecting a generator to a bus node, both the generator and the bus node have already been placed in the ship design, but the connecting equipment such as cables, isolation devices, and converters are not yet instantiated. The template segment for this connection will have fully parameterized components for the connecting equipment, but a blank dummy component for the generator and the bus node. All components in the template, including the dummy components, will be fully connected.

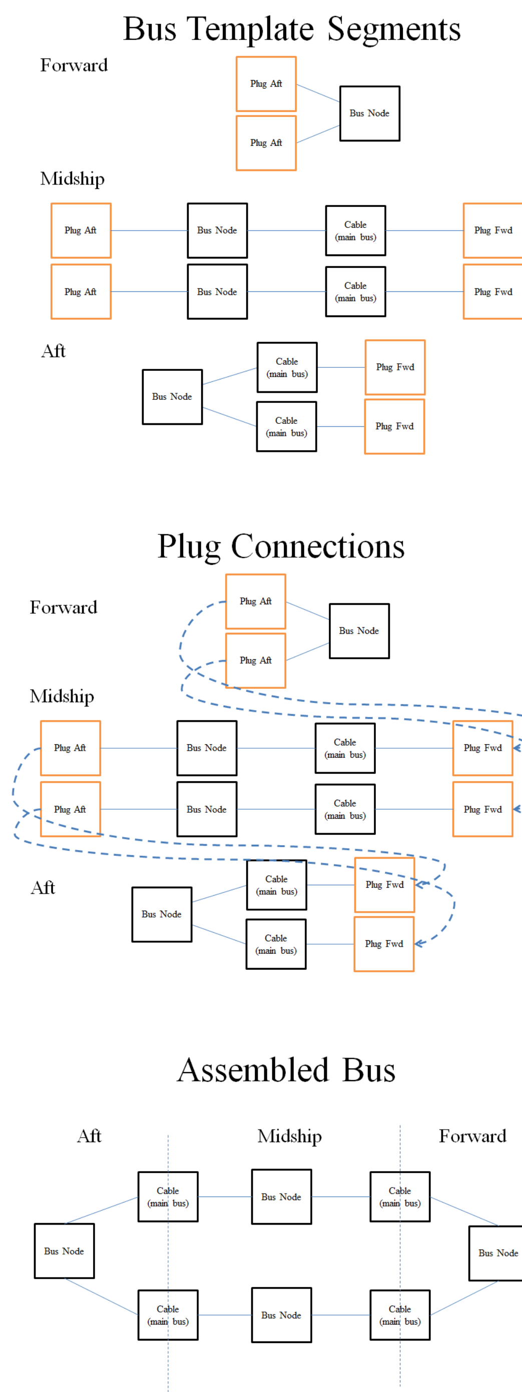

Figure 6. Power corridor backbone assembly.

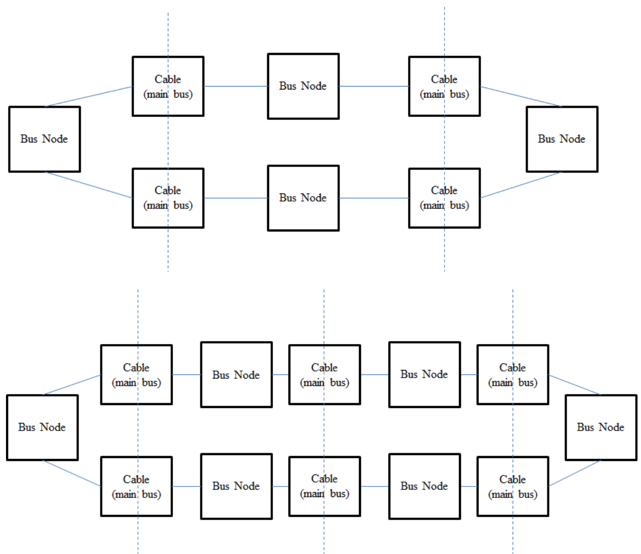

Figure 7. Three-zone (top) and four-zone (bottom) examples of applied templates.

When the template segments are copied into the ship model, the dummy blank components are replaced with the existing component and all connectivity to the dummy components is transferred to the existing component. This process is presented in Figure 8.

C. *FOCUS Compliance*

When the template segments are originally created and stored in a LEAPS database, they are as fully parameterized as is possible without placement in a ship model. Some definitions [2] may be helpful at this point:

A LEAPS Concept contains a particular version or configuration of a product, usually a single ship design. Each variant of the design would be stored in a separate concept.

A LEAPS Common View is a categorization of data within a concept; a common view can contain components, properties and geometric information. Common views are used to aggregate information in categories such as component categories (e.g. appendage components, HVAC components), component types (e.g. electric motor components, rudder components), geographical location (e.g. all equipment in a specific zone or compartment, or all weather-exposed equipment), geometric information (e.g. all surfaces that make up a bulkhead), etc.

A LEAPS System is a collection of components, connections and properties that accomplish a function, e.g. climate control or electric power distribution. LEAPS Systems may contain a Diagram which records connectivity. Systems may also contain sub-systems. A single Component may belong to multiple Systems.

Connectivity between components is stored in LEAPS using ports, terminals, and various types of connections, all linked to a diagram. This connectivity is described further in [5] and [7].

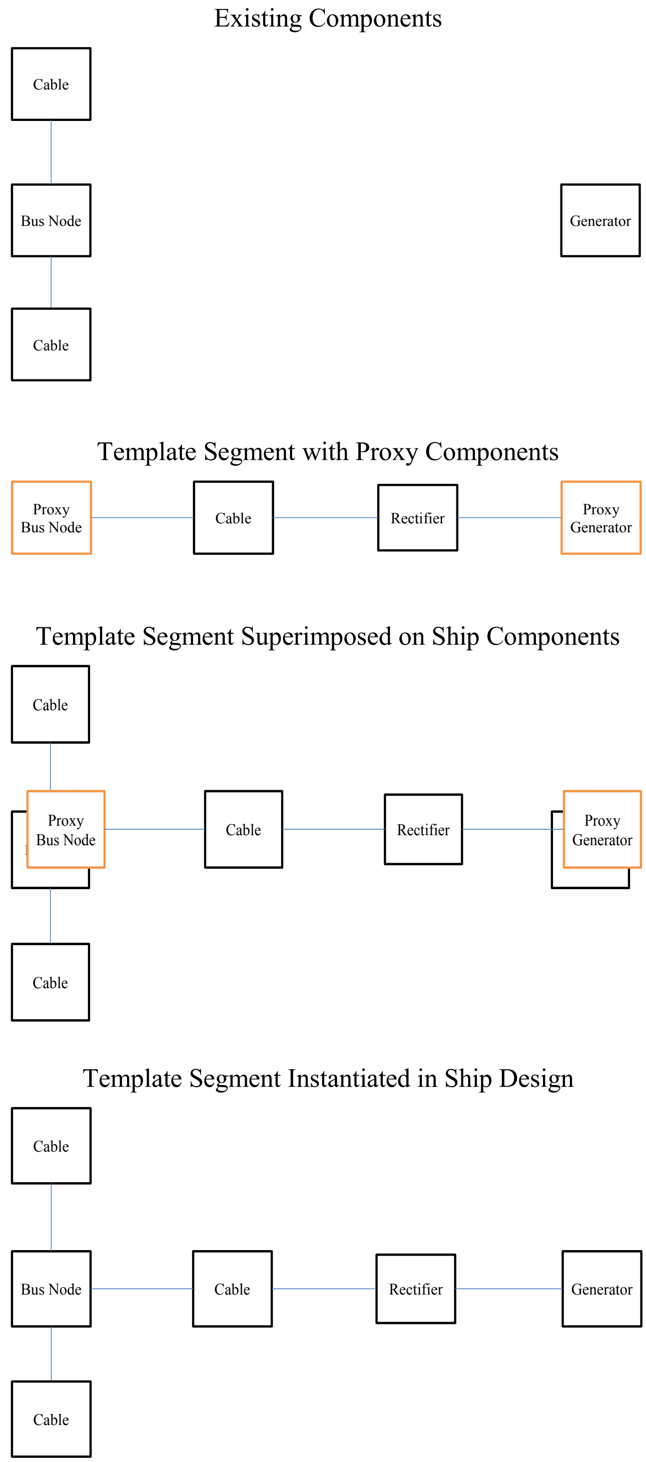

Figure 8. Connecting sources and sinks.

A fully parameterized template segment will thus consist of several components with all possible properties populated. The components are fully connected to one another using ports, terminals, connections and diagrams, and are placed in the proper systems and common views. The template segment is stored in LEAPS as a Concept.

When the template segments are copied into the ship, all components and their properties are copied into the ship design concept, all connectivity is replicated, the components are assigned to common views and systems, and the appropriate additional properties and common views, such as location and zone, are populated.

D. Equipment Location

Equipment is roughly located in three-dimensional space in the ship during this initial logical connection, but the placement is accomplished without ensuring that there are no overlaps between components or with ship structure. Such conflicts are resolved later in the templating process. Similarly, components whose size depends on location in the ship, e.g. cable length, are assigned an initial value during this step but refined later.

For template segments that are completely copied and pasted into a ship, such as the segments of the power corridor backbone, the components are arranged relative to one another in three-dimensional space in the template using a local template coordinate system; when copied into the ship, they are arranged in the same position relative to the zone's coordinate system adjusted to the size of the zone.

For template segments that connect two already instantiated components such as a template segment that connects a generator to the power corridor, the new components are distributed evenly between the two extant components, without regard to overlap. Conflicts are resolved and final positioning is accomplished after all equipment is roughly placed.

The output of this process is a fully-connected, FOCUS-compliant electrical distribution system stored in LEAPS with established systems and common views properly populated, and with equipment roughly placed in 3D space.

VII. In Progress: Equipment Sizing

Until an electrical distribution system is placed in a ship with the generators, loads and energy storage modules connected, the amount of power that flows through any one component is unknown. Similarly, the amount of water in a liquid cooling system or the amount of heat in an HVAC system is unknown. Another effect of smaller impact that cannot be calculated until the system is placed in a ship design is the change in resistance that occurs in connecting equipment such as cables or piping with changes in length. Therefore, once the system is logically arranged in the ship, we use this arrangement to determine the flow in each component.

There is significant research into optimizing the number and size of connections in a network as applied to terrestrial electrical grids and even shipboard electrical distribution systems, see [8] and [9] for a couple examples. Since the problem of determining connections is much less tractable than determining the flow through an established network, these methodologies are computationally much more expensive. At this point we leave the network design as a preliminary step used to generate possible configurations that are then employed in the ship-wide set-based design process. We seek instead a methodology to size the network components; the methodology must be very fast and of sufficient accuracy for early-stage ship design.

A properly connected system design stored in LEAPS lends itself to extraction of a graph or network describing the system, thus opening the possibility of graph-theory applications. We exploit this functionality to create an adjacency matrix of the system which is used to determine the maximum possible flow through any component. Although load-flow algorithms provide a more accurate view of the power flow in a system, they require significantly more computational complexity and time. The inaccuracies in a linearized graph-theory analysis can be compensated for through the judicious application of design margins. Alternatively, graph-theory applications can elucidate stressing conditions that can be further explored using load-flow or fully dynamic analysis.

The process for determining the power rating for each component is as follows. An adjacency matrix is extracted from the LEAPS system representation and resistances are applied to each edge of the graph. Minimum cost algorithms find the path from each load to each generator, and the highest load in each connection is retained for each possible operational alignment. The component capacity (rated continuous current or rated power) is set to this highest load value. More details on the process for extracting a graph and determining flow through a network are provided in [7].

VIII. Future Work: Equipment Positioning and Conflict Resolution

The physical positioning of equipment, collision detection, and the resolution of interferences is planned for future work. Equipment is initially positioned using zonal divisions and user input for the power corridor locations; this initial positioning ignores equipment overlaps. Collision detection will be used to determine equipment overlaps, and resolution of overlaps will be investigated.

IX. Conclusion

The work described herein takes a significant step toward implementing a semi-automated methodology for populating ship designs with fully-connected and parameterized ship systems ready for analysis and simulation. The designer controls the process through selection of templates and application protocols, thus steering the design while allowing the RSDE process to automatically populate myriad ship hulls in a broad design-space exploration. The tool under development is LEAPS- and FOCUS-compatible and thus ready for implementation with the Navy's early-stage design tools.

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