

INTERIM REPORT ON S3D/LEAPS INTEGRATION

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Interim Report on S3D/LEAPS Integration
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Abstract

The Naval Surface Warfare Center Carderock Division has created the Leading Edge Architecture for Prototyping Systems, or LEAPS, as the data repository for ship design, and a significant number of the early-stage ship design tools interface directly or through a translator with LEAPS. Separately, the Office of Naval Research has funded Smart Ship Systems Design (S3D), a ship design tool effort that expands the Navy’s toolkit to include simulation and distributed system design among other capabilities. The current project will integrate S3D with LEAPS. This report provides an interim status report on progress for the integration project. The project plan and use case are described, underlying terms are defined and correlated between the two databases, and the initial version of the translator code is described.

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Introduction

The Navy’s primary early stage ship design tools support Naval Architects in capturing ship mission requirements and integrating ship engineering disciplines to synthesize a basic ship design and predict physical and performance characteristics. The Advanced Ship and Submarine Evaluation Tool (ASSET) produces produce a ship model that details weight and space characteristics, hull resistance and propulsion, and structural integrity. Additional tools provide refined analysis of hydrodynamics including resistance and seakeeping, intact and damaged stability analysis, manning estimates, cost estimates, space arrangements, and others.

The Navy has identified the importance of capturing product model data, including modeling and simulation efforts, as a means to realize substantial savings during the design, construction, and service-life support of a ship [1]. The capturing, consolidating, and organizing of this data in a single persistent store leads to better integration and an overall reduction in engineering effort when engineers need to locate, verify, and transform information for a design. A team at Naval Surface Warfare Center Carderock Division (NSWCCD) developed the Leading Edge Architecture for Prototyping Systems (LEAPS), which is a stable, controlled, extensible product modeling environment [2] that is used to maintain the current state of the ship design throughout the ship design process. The goal is for LEAPS to become the repository of the ship design throughout the entire life cycle.

One capability that is missing from the current LEAPS suite of design tools is the ability to lay out distributed systems in the proper shipboard arrangement and perform simulations on the resultant systems to ensure the capability to meet the demands of the mission requirements. With the advent of electric ship and the increased interoperability of ship systems, the ability to run simulations earlier in the design cycle is becoming much more important. Smart Ship Systems Design (S3D), developed by the Electric Ship Research and Development Consortium (ESRDC), meets this need.

The Office of Naval Research (ONR) has contracted with ESRDC to develop a design tool that facilitates design and simulation of shipboard distributed systems including analysis of the interactive and ship-wide effects of the distributed systems. The resultant prototype design environment, Smart Ship Systems Design (S3D), is a collaborative, cloud-based, multi-disciplinary, concurrent engineering ship design tool. Engineers work in discipline-specific design spaces concurrently operating on the same repository of ship data, and can respond in real time to changes made in other disciplines that affect their design. The toolset supports development and basic simulations in electrical, piping, mechanical and HVAC disciplines, while also providing a 3D arrangement tool for placement of equipment. The environment also provides a gateway to more in-depth system simulation. Additional features of S3D that are beneficial to the LEAPS suite of tools are the operational scenario simulation capability, and the equipment catalog that has been developed. S3D could also act as an interactive, graphically based editing tool for a ship design and associated equipment stored in LEAPS.

If S3D is to be used to enhance the current LEAPS toolkit by laying out and simulating systems, then the data from S3D that is persisted within LEAPS must include the equipment and connectivity of the distributed systems, the information required to repeat simulations rapidly and easily, and the results of any simulations run including the state of the equipment during the simulation.

Ability to re-run simulations, gateway to higher fidelity simulations

S3D benefits from integration as well. Thus, they can use the well-developed naval-architecture specific tools for initial ship synthesis and integration, hullform and superstructure design, and analysis including, for example, resistance, stability and seakeeping prediction, and manning and cost estimating.

Integration with Navy Design Tools

Navy early-stage ship design tools interface with the LEAPS repository in two ways: some of the tools use LEAPS as an integrated repository, while others incorporate translators which allow for the extraction and insertion of data into LEAPS. The ultimate goal for the LEAPS/S3D integration is for S3D to use LEAPS as the integral database. The intricacies of this goal will be discussed later in this paper. While working toward a fully-integrated version, we will first develop a translator. This is more rapidly achievable and the techniques and knowledge developed within this effort will inform the later full integration of the two systems.

Using the LEAPS Application Programmer's Interface (API), it is possible to both extract information from a LEAPS database for use in an external program and inject information that has been developed externally into the LEAPS database. The translator we are developing will accomplish both these functionalities in relation to the S3D toolset. The first step in this process is to assess and document pertinent data and structures that exist in LEAPS and S3D and develop a plan for representation of items in each format. We will then modify the S3D database as required to support the new representation and employ the LEAPS API to develop the translator. We will then exercise the translator by accomplishing ship design using both LEAPS and S3D to verify proper functioning. Follow-on work will include improving the robustness of the data in the S3D repository through production of ship hulls and other data in external programs and providing them to S3D via the translator.

Process

The following is an envisioned process for the use of LEAPS and S3D in conjunction with one another, using a translator.

First, a ship will be initiated using ASSET and stored in LEAPS. Additional analysis may be conducted using other programs in the LEAPS toolkit.

The ship concept will be read from LEAPS and stored as a design in S3D. Imported information will include:

- Hull and superstructure geometry
- Bulkhead & deck locations
- Locations and attributes of equipment
- Connectivity information
- Speed/power curve

The design will be fleshed out within S3D to allow simulation. This may include instantiation of additional equipment, establishing connectivity, assigning values to necessary attributes that are not populated, and arranging equipment in a 2D line diagram and in 3D space. Some equipment that comes from LEAPS may need to be deleted, replaced, or modified.

Power flow simulations will be run within S3D and results will be logged. In addition, operational scenarios may be tested.

At completion of the simulations and at any other time during the design process, the design within S3D can be written to LEAPS. The information written will include updates to existing equipment, new equipment, connectivity, simulation states, and simulation results.

This process requires updates to both the LEAPS and S3D format.

In the fully-LEAPS-integrated version of S3D, it is envisioned that all changes to the design performed in S3D will be automatically and immediately stored in LEAPS. In the interim, it will be necessary to track which equipment items are which while being manipulated in S3D.

Plan

More in-depth analysis of the work required to integrate S3D and LEAPS lead to the following plan and schedule.

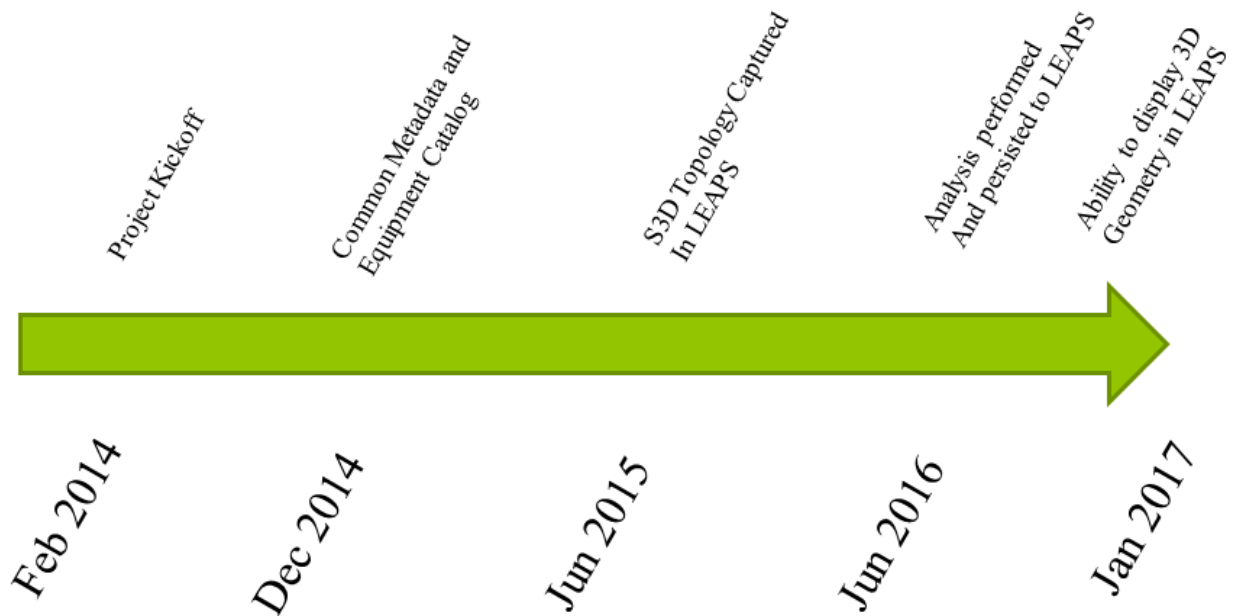


Figure 1 Project Timeline

Familiarization/Background (Feb 2014). This involved familiarization with all software involved and ensuring all team members had access to the latest versions and to the LEAPS API, the application framework and the S3D façade, and administrative details such as setting up email listings and sharepoints. We also had initial discussions on how the two databases were set up and clarified things such as the inheritance process, database structure, language, header files, and terminology. We also reviewed the current equipment catalog in S3D and purged any unneeded attributes.

Read/write Components to/from LEAPS/S3D (Feb-Dec 2014). This is the correspondence of components (actual pieces of equipment placed shipboard) and the attributes or properties associated with them. The first step is a data dictionary that clearly delineates the definitions of terms, equipment and properties in each software and draws correlations between the two. This dictionary will also allow us to clearly delineate what components or properties need to be added to either FOCUS or S3D. In addition to the components and properties, we will include bounding box data, orientation, location and scale of the components. At present, there is valuable data in the payload and adjustments table; in future versions of ASSET, the payload items will be treated as components.

One area that requires additional definition within LEAPS/FOCUS is a methodology for storing distributed equipment such as cable and piping which may have a pre-set diameter, but the length is determined by the application. Currently there is no convenient way to store such items in LEAPS/FOCUS.

Read/write Ship Behaviors and ship-wide information (Oct 2014 - Feb 2015). The next type of information to be addressed after individual components is information that pertains to the entire ship and behaviors. This information includes such things as a speed/power curve, maximum, sustained and cruise speeds, range, fuel load, tankage, bulkhead and deck locations, and area, power and cooling summaries.

Read/write System Data and Topology (Aug 2014-May 2015). The next area of information to be addressed is systems, including connectivity. Included in this portion of the task is the representation of system line diagrams in 2D.

Analysis performed and persisted to LEAPS (Jun 2016). The purpose of this integration is to provide a simulation capability to the LEAPS toolkit; persisting the necessary information is this task. In order to accomplish this, we must determine what simulation state information should be retained, what data from the simulations should be retained, and the format for the simulation output.

Read/write Ship Geometry (Jan 2017). This includes 3D geometry of the ship hull, deckhouse, bulkheads, decks and compartments, plus the models of individual pieces of equipment. LEAPS represents all geometry using NURBS curves and surfaces; S3D uses a meshed 3D model. While it is straightforward to go from the NURBS representation to a meshed visualization, it is extremely difficult to go in the other direction. For this reason and since fairly robust hullform modeling tools exist in the LEAPS toolkit, it has been decided that all ship geometry manipulation will be accomplished in the LEAPS suite of tools.

Progress

Significant effort has gone into determining how the different components of LEAPS and S3D are defined and stored, which items in LEAPS and S3D correlate to one another, and how the two systems create and manipulate the different portions of a design. Thus, much of the rationale and groundwork behind the code has been formulated.

Definition and Correlation of Data Type Terminology

Table 1 DRAFT Correlation Matrix for S3D/LEAPS Terminology

LEAPS	S3D
Study	Project
Concept	Design
Catalog	Equipment Catalog*
(no LEAPS equivalent)	Equipment Type Category
Component Item	Equipment Type*

Component	Equipment Item*
Property	Attribute
Property Item	Attribute Item
System	Discipline View*
Common View	(no S3D equivalent)
Property Group	(no S3D equivalent)
Material / Material Item	(no S3D equivalent)
Tool / Tool Item	(no S3D equivalent)

* not an exact one-to-one correlation, but similar concepts

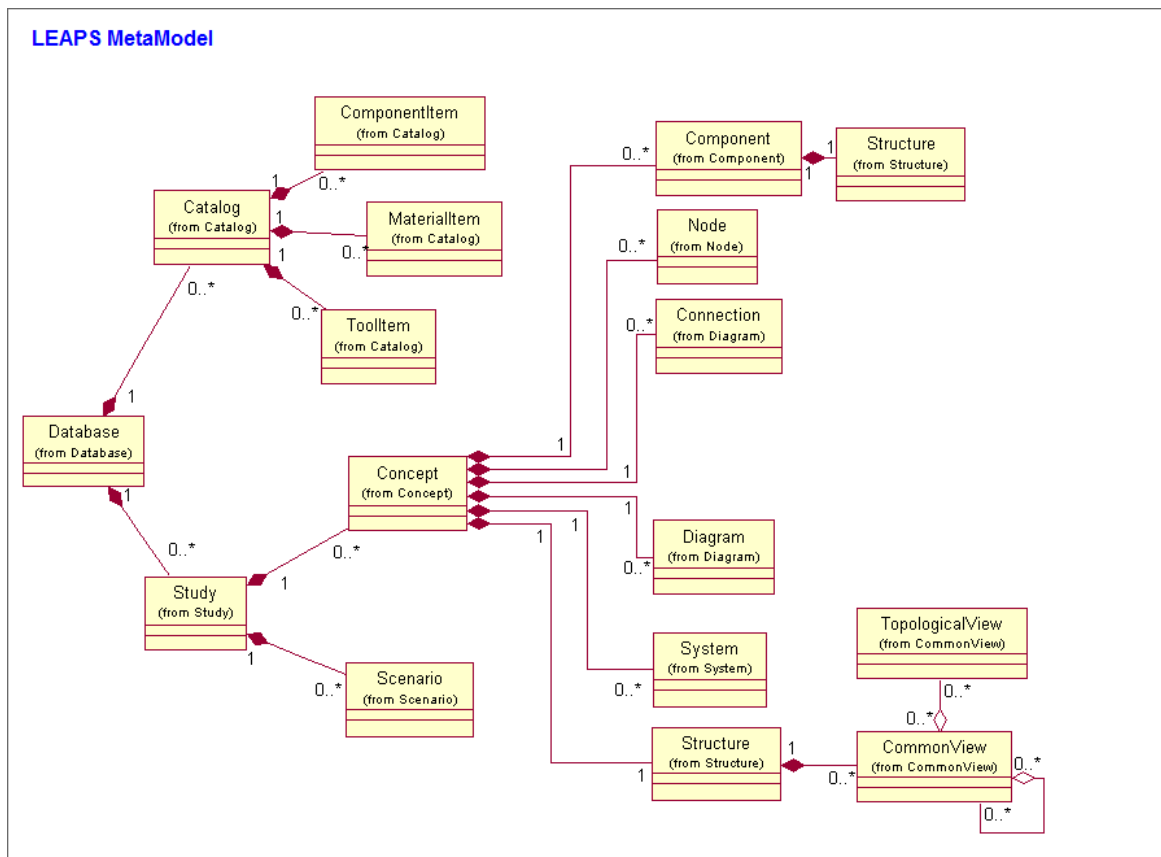


Figure 2 LEAPS MetaModel Diagram [3]

Figure 2 shows the structure of the LEAPS Metamodel. Correlating terms from S3D are shown in Table 1 and described below (all definitions of LEAPS items in the following list are quoted directly from the LEAPS User's Manual [3]):

A LEAPS database is “the highest level object that contains one or more product models and resides on a piece of hardware or storage device as a collection of permanent files.” The S3D equivalent is the entire S3D database.

A LEAPS Study is “a container comprising one or more similar or related products/models, qualified by operational requirements or environmental conditions (Properties and Scenarios) (example: DDG-51).” The equivalent concept in S3D is the Project.

A LEAPS Concept is “a container comprising a particular version or configuration of a product, as qualified by particular set of operational requirements or environmental conditions (example: Flight I, Flight II).” The equivalent concept in S3D is the Design, which will be a single ship design.

A LEAPS Catalog is “a repository for collecting part or data items (Catalog Items) for reuse in one or more Studies; it minimizes resource (memory, database size) loads since instantiating an object from a Catalog item is accomplished by a reference pointer to the item in the Catalog and does not result in a value copy.” There can be multiple LEAPS catalogs within one LEAPS database. The equivalent concept in S3D is the equipment catalog, and a related concept within S3D is the metadata tables, such as the lists of units, vendors, etc., to which pointers are directed.

A LEAPS Component is “a piece or sub-part of a product model which may or may not contain geometry other than molded form geometry (examples: pump, engine, table).” A Component can be instantiated either as a pointer to a ComponentItem in a Catalog, or as a stand-alone Component not associated with a Catalog. The S3D equivalent is an Equipment Item; however, within S3D there is a mandatory hierarchical parent/child association in which an Equipment Item inherits from an Equipment Type which inherits from an Equipment Type Category. In addition, an equipment type will usually have a component item associated with it; the S3D component item is a simulation engine and 2D icon. There can be multiple component items associated with a single equipment item for different disciplines (for example, a water-cooled gas turbine generator will have an electrical simulation model, a thermal simulation model, and a mechanical simulation model).

A LEAPS Property is “a piece of information or data that provides characteristic attribution for an object (examples: weight, manufacturer, signal-to-noise ratio).” A Property can reference a PropertyItem or a Property within a ComponentItem in a Catalog, or a Property can be stand-alone. The S3D equivalent is an attribute; however, all S3D attributes associated with a piece of equipment are instantiated as pointers to master Attribute Types.

A discussion of units is necessary. In S3D, there is a metadata table of possible units. When an attribute is created and put in the list of Attribute Types, a pointer to a unit is assigned. This unit can only be changed by changing the unit pointer in the attribute type. In FOCUS, each property is assigned a unit within the pmm file, and the units cannot be changed.

A LEAPS System is “a physical or functional aggregation of parts, characteristics, and connectivities that is designed to perform or contribute to a task (examples: seawater piping system, torpedo handling system, shipboard communication system).” While there is no exact correlation within S3D, the S3D “discipline views” are a related concept. A discipline view is a subset of the equipment in the design that is pertinent to a single discipline, such as electrical, mechanical, piping, or HVAC. S3D also includes the concept of a sub-system.

A LEAPS Scenario provides “the operational situation in which the Concepts of the Study are required to operate. The operational situation provides the context of how the Concepts are to be evaluated and the measures of effectiveness.” This is analogous to an S3D Mission.

A LEAPS Node “represents a location in space that may have attribution associated with it.” An S3D Node is equivalent. The LEAPS node structure is under refinement.

A LEAPS Connection describes “the connectivity of the ConnectionMember objects comprising the Connection and the type of connection modeled. A connection can be serial or parallel.”

A LEAPS Diagram “provides a schematic of the connectivity information about a LEAPS System.” This is analogous to the S3D system one-line diagram, although the S3D version is restricted to the discipline views.

There are LEAPS terms which do not have equivalents in S3D, including the following:

A LEAPS CommonView is “a logical collection of data which may or may not contain geometry, such as, volumes, surfaces, shapes (example: compartments, subdivisions, hulls, deckhouse, weather-exposed structure).” An S3D equipment item includes a 3D CAD file which addresses the geometry part of this, and it is possible to query the design in an S3D database to obtain information available to some common views, e.g. “all aluminum parts” or “all components with a SWBS”.

A LEAPS PropertyGroup is “a container for a logical collection of Properties (geometry not allowed).”

A LEAPS Material collects attributes describing the behavioral characteristics of a material used in the modeling of a product or part of a product. It can be stand alone or a pointer to a MaterialItem in a Catalog.

A LEAPS Tool is a descriptive attribute that may be associated with any LEAPS object and is intended to describe a program, application or approach that is responsible for the creation or derivation of the parent object. It can be stand alone or a pointer to a ToolItem in a Catalog.

The LEAPS Geometry Object Structure (GOBS) “allows computer-aided design (CAD) system geometry and attributes to be presented to various engineering designers and analysts in a context which allows for convenient discretization or manipulation with respect to their domain requirements. The GOBS modeling concept develops a geometric product model that is defined and represented as logical subsets or "views" of geometric objects, unlike most CAD representations where the geometry defines the view and the object simultaneously. In addition, GOBS creates associations between related geometry objects to define connectivity along common boundaries, such as the intersection at a deck edge and the hull. The GOBS process imparts “knowledge” to the various geometric entities representing the deck and the hull, such that they each know they are connected to the other object and where that connection occurs.” S3D geometry is represented as 3D CAD files and cannot be broken down into smaller segments or built up into larger structures.

Language/Version of Components and Associated Compatibility Issues

All the software that is involved in this process is currently under development and improvement. The LEAPS data repository and the FOCUS model are guaranteed to be backwards compatible – they may be expanded, but will not be changed in a way that makes terms obsolete or data stored in previous versions inaccessible or unusable. Therefore, any

recommended changes to the FOCUS model or expansions to LEAPS must be fully vetted before being incorporated.

In the near future, LEAPS and the LEAPS toolkit programs (ASSET, IHDE, etc.) will become cross-platform compatible and will be able to be run on PC and Linux, with Mac envisioned soon after. LEAPS is written in C++, and the current version available to the developers in this project is compiled in Visual Studio 2010. S3D is written in C#, which is a managed C code that is available on Windows platforms only. C# was selected because managed code is beneficial in an environment in which many students are involved in the development process. Additionally, the web interface is run in Silverlight, another Windows-centric program, and the current development environment for S3D is Visual Studio 2013.

Component Translator

The first step is to read components (physical pieces of shipboard equipment) from LEAPS, translate the names and properties to S3D terminology, and populate a model in S3D using the LEAPS equipment. After manipulation of the design in S3D, components are then read from S3D, translated to LEAPS terminology, and stored in LEAPS.

Due to some incompatibilities between the different versions of Visual Studio and between C++ and C#, an interim layer is being implemented in order to develop the code until the versions of the codes become more compatible. The format of this translator is shown in Figure 3, and the steps are discussed in more detail below.

Exporting components from LEAPS

Using the API, we export all components from LEAPS to a text format (json). Associated with each component, we export the following:

- Identification: each component is named with a Unique ID which, in order to be FOCUS compliant, must include the standard component name followed by an integer number.
- Common characteristics, which are standard properties that can be associated with any component; examples include functional description, SWBS number, and weight.
- Component unique characteristics, which are properties that can only be associated with that specific type of component; e.g., engine RPM and engine SFC curve can only be associated with engine components.
- Geometric properties: while we are not extracting 3D geometric models of equipment at this point (geometry will be addressed in the third year of the contract), we can currently extract the bounding box dimensions of the component, the location, and the orientation.
- Data types that are currently extracted include integers, floating point numbers, strings, and vectors of integers, floats, and strings. The remaining data type to be extracted is splines; LEAPS uses a NURBS format, while S3D uses a 2D array.

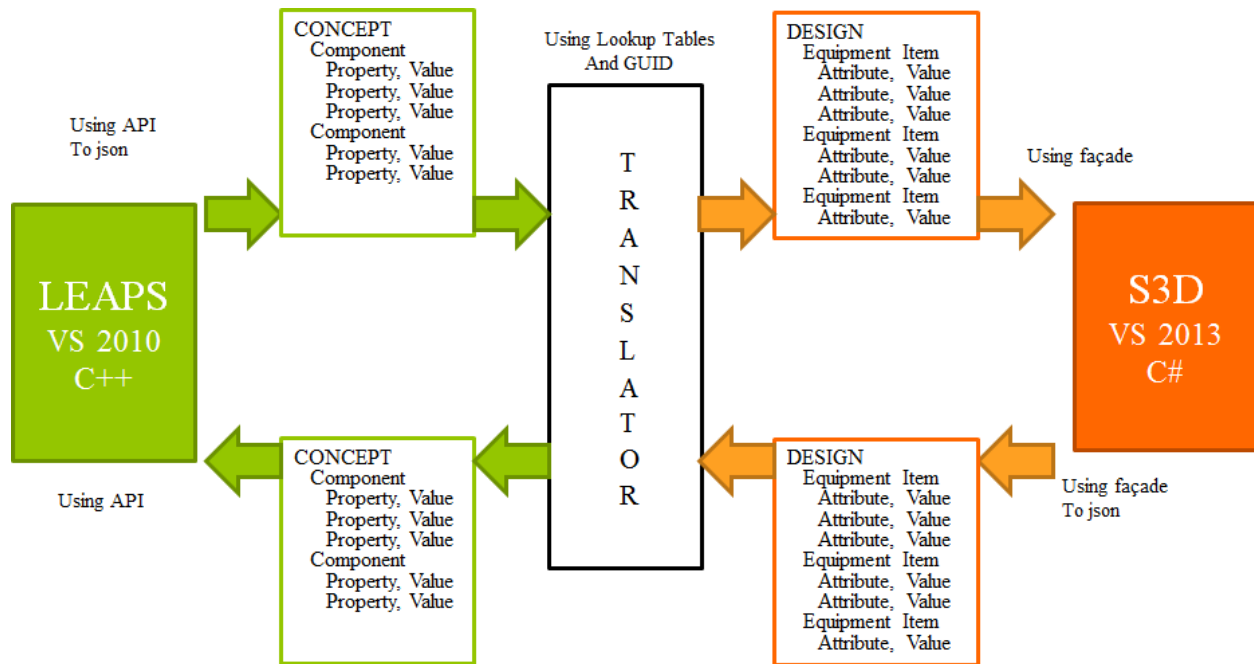


Figure 3 Translator Initial Format

When reading a component from LEAPS, it is important to instantiate the proper equipment in S3D, since the S3D version of a component includes a simulation model tailored to that type of equipment. There is a one-to-one mapping for a few pieces of equipment between S3D to LEAPS, but most equipment has either a one-to-many or a many-to-one mapping that complicates this process. For example, a LEAPS component “generator_” can be instantiated in S3D as either a “_Generator (Liquid Cooled)” or a “_Generator (Air Cooled)”, so the cooling methodology must be determined in order to select the proper S3D model.

References

- [1] Doerry, N. “A Vision for Ship Design and Analysis Tools,” Marine Technology, pp:8 July 2012.
- [2] Leading Edge Architectre for Prototyping Systems, LEAPS, An Overview. Distribution Statement A: Approved for public release; distribution is unlimited. Downloaded from <http://www.navsea.navy.mil/nswc/carderock/pub/who/departments/leaps.aspx> Sept 2014.
- [3] LEAPS Version 4.5 Application Programmer’s Interface User’s Manual. Carderock Division – NSWC Design Tool Development Branch. Statement A: Approved for Public Release; Distribution is unlimited.