Advanced Design Tools for Ocean Energy Systems Innovation, Development and Deployment

Deliverable D7.1

Standard Data Formats of Ocean Energy Systems

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EXECUTIVE SUMMARY

Deliverable D7.1 "Standard Data Formats of Ocean Energy Systems" of the DTOceanPlus project is a report, collecting the outcome of the work carried out during task T7.1 of the project, aiming at fully describing the data used for a generic ocean energy system design in a structured manner. This has been done by means of the definition of a Digital Representation for the elements of the whole system at different levels of aggregation (i.e. array, devices, sub-systems, and components) and accounting for different levels of complexity of the project. The ambition of the present framework is to standardise the data formats describing an ocean energy design so that it can be used as a common interchange language among different sector actors. This means that the scope of the present digital representation for Ocean Energy Systems is not going to be limited to the DTOceanPlus project.

In order to fully capture the main aspects of an ocean energy system, the present digital representation framework has accounted for:

- Elements of the technology design (physical domain), phases of the technology lifecycle (process domain) and constraints from the context (external environment)
- A vertical dimension, that describes a set of hierarchical connections among subsystems and components,
- A transversal dimension, accounting for the individual and specific components of the system.

The present deliverable describes the needs, features and structure of the Digital Representation, and provides some actual implementation examples. The data formats for each subsystem of the representation have been included and described in the annex.

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ABBREVIATIONS AND ACRONYMS

BIM	Building Information Modelling
CAPEX	Capital Expenditure
CED	Cumulative Energy Demand
DFIG	Doubly-Fed Induction Generator
DNV GL	Det Norske Veritas Germanischer Lloyd
DR	Digital Representation
D&A	Deployment and Assessment Design Tools
EC	Energy Capture Deployment Design Tool
ED	Energy Delivery Deployment Design Tool
ESA	Environmental and Social Acceptance Assessment Design Tool
ET	Energy Transformation Deployment Design Tool
ETIP	European Technology and Innovation Platform
GWP	Global Warming Participation
HDFS	Hadoop Distributed File System
IEA	International Energy Agency
IFC	Industry Foundation Classes
IUCN	International Union for the Conservation of Nature and Natural Resources
JSON	JavaScript Object Notation
LCOE	Levelized Cost of Energy
LMO	Logistics and Marine Operation Deployment Design Tool
MTTF	Mean Time To Failure
OES	Ocean Energy System
OPEX	Operational Expenditures
PTO	Power Take off
RAMS	Reliability, Availability, Maintainability and Survivability Assessment Design Tool

RDS-PP	Reference Designation System for Power Plants
SC	Site Characterisation Deployment Design Tool
SCIG	Squirrel Cage Induction Generator
SG	Stage Gate Design Tool
SI	Structured Innovation Design Tool
SK	Station Keeping Deployment Design Tool
SLC	System Lifetime Costs Assessment Design Tool
SPEY	System Performance and Energy Yield Assessment Design Tool
TRL	Technology Readiness Level
US	United States
UTM	Universal Transverse Mercator
WEC	Wave Energy Converter
WP	Work Package
XML	eXtensible Markup Language
YAML	Yet Another Markup Language

1. INTRODUCTION

1.1 SCOPE OF THE REPORT

Deliverable D7.1 "Standard Data Formats of Ocean Energy Systems" of the DTOceanPlus project is a report, collecting the outcome of the work carried out during task T7.1 of the project, aiming at fully describing the data used for a generic ocean energy system design in a structured manner.

The description of the Digital Representation for Ocean Energy System is one of the expected outcomes of the DTOceanPlus project (see Section 1.3) and it has been the result of Task 7.1, but also from a user consultation (see Section 1.2) and other actions during the project.

In the present document:

- The needs and requirements of the different users, the conceptual framework and experiences from other sectors are described, in order to put the present work in the current context in the renewable energy sector;
- The architecture of digital representation for Ocean Energy Systems is later on described;
- Finally, the different objects of the digital representations are described, with a list of attributes defining their properties.

As with the overall DTOceanPlus project, the scope will cover the two more developed sources of ocean energy, namely tidal stream and wave energy.

1.2 METHODOLOGY

The process of creating the Digital Representation (DR) involves a series of interlinked activities with the objective of producing a comprehensive definition of standard data formats for Ocean Energy Systems. This process can be summarised in the following main phases:

- **General concept**. Introduced at the proposal stage to provide a tool that facilitates sector stakeholders to work collaboratively.
- **User consultation**. The user group needs and expectations of such a digital framework were defined in greater detail in the early stages of DTOceanPlus project (WP2). The outcome of this survey can be consulted in [1]. This served to identify the context and the structure that such a framework would adopt.
- **Concept development**. Consortium partners transformed the operational and functional requirements for such a framework into a full design for the Digital Representation (WP7). Outcomes of this phase are mainly described in this deliverable. It basically consists on filling such a framework with the set of digital objects for Ocean Energy Systems.
- **Practical implementation**. The first implementation of the DR will be provided with the final release (WP7). It involves concept improvements following the application to several validation scenarios.

- **Dissemination and training**. In parallel to the implementation phase, periodic dissemination and training actions are being organised (WP9) to raise awareness and gather feedback/recommendations from different stakeholders to expand its implementation.

At project end, the DR will be integrated in the DTOceanPlus suite of tools and its use offered to other stakeholders and software developers free of charge.

1.3 SUMMARY OF THE DTOCEANPLUS PROJECT

DTOceanPlus will accelerate the commercialisation of the Ocean Energy sector by developing and demonstrating an open source suite of design tools for the selection, development, deployment and assessment of Ocean Energy Systems (including sub-systems, energy capture devices and arrays).

At a high level, the suite of tools developed in DTOceanPlus will include:

- **Structured Innovation Tool (SI)**, for concept creation, selection, and design.
- **Stage Gate Tool (SG)**, using metrics to measure, assess and guide technology development.
- **Deployment Tools**, supporting optimal device and array deployment:
  - Site Characterisation (SC);
  - Energy Capture (EC);
  - Energy Transformation (ET);
  - Energy Delivery (ED);
  - Station Keeping (SK);
  - Logistics and Marine Operations (LMO).
- **Assessment Tools**, to quantify key parameters:
  - System Performance and Energy Yield (SPEY);
  - System Lifetime Costs (SLC);
  - System Reliability, Availability, Maintainability, Survivability (RAMS);
  - Environmental and Social Acceptance (ESA).

These tools will be supported by underlying common digital models and a global database. In fact, the so-called Digital Representation will provide a standard framework for the description of sub-systems, devices and arrays, thus allow sharing of design information.

The DTOceanPlus software tools are illustrated at a high level in Figure 1-1.

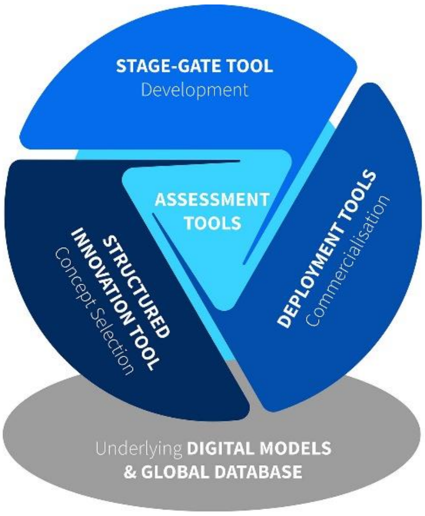

FIGURE 1-1: REPRESENTATION OF DTOCEANPLUS TOOLS

1.4 OUTLINE OF THE REPORT

The present deliverable consists of the following sections:

- **Section 2** describes the conceptual framework for the Digital Representation developed within DTOceanPlus, defining the problem addressed as well as reviewing the experience from other sectors and the main characteristics of the current framework;
- In **Section 3**, the structure of the current framework is described, and a couple of examples are provided. The last subsection includes a review of the implementation challenges of this framework.
- **Section 4** provides an overview of the future work.
- Finally, the annex in **Section 6** describes in detail the various subsystems and the attributes that define them in the digital representation.

2. THE CONCEPTUAL FRAMEWORK FOR THE DIGITAL REPRESENTATION OF OCEAN ENERGY SYSTEMS

2.1 PROBLEM ADDRESSED

The overarching objective of the DTOceanPlus project is to develop and demonstrate an open source integrated suite of 2nd generation design tools for ocean energy technologies that supports the entire technology innovation process. It is intended that DTOceanPlus will aid the ocean energy sector in replicating the success that other sectors have had in achieving commercialisation. Methods by which other sectors have reduced technical and financial risks are being assessed, adapted and imported to the Ocean Energy sector.

One particular need in Ocean Energy is that **there is currently no standard method of describing the key characteristics and attributes of Ocean Energy technologies**. Without such a standard, it can be difficult, if not impossible, to objectively analyse innovative technologies and compare competing technologies. This hinders the ability of the Ocean Energy sector to engage in knowledge sharing activities and focus limited funding and resources on only the most promising technologies. Thus, the Digital Representation has been conceived with the main objective of providing an industry standard for communicating technology descriptions (both physical and functional characteristics) throughout the sector.

One of the objectives of the Water Power Programme funded by the US Department of Energy [2] was to support the development of a standard taxonomy in order "to reduce the technical barriers to marine and hydrokinetic device development, to improve device reliability and performance, and to understand and evaluate various technology types". In the case of wave energy, a breakdown of a wave energy system is presented in [3] and [4]. A Wave Energy Converter (WEC) is decomposed in a few common discrete subsystems, based on a functional approach, i.e. identifying a list of functions that the WEC system should perform. Five major subsystems have been identified (namely, hydrodynamic system, PTO subsystem, Instrumentation and Control, Power transmission, and Reaction Subsystem). However, the technological taxonomy focused only on the structural design, neglecting the operations inherent to these operations and the related logistics.

Likewise, Bull et al. [5] presented an effort to apply a Systems Engineering Process approach to wave energy systems in order to identify capabilities and functions of a wave farm. In this work, after identifying a mission statement for a wave energy farm (cit. "*The wave energy farm will convert ocean wave energy to electricity and deliver it to the continental grid market in a competitive and acceptable manner across the lifecycle*"), a hierarchical structure for capabilities and functions was built, encapsulating the stakeholder perspective and design agnostic elements required to satisfy user's requirements. Even though this approach is not technology related, it comprises the entire lifecycle of a wave energy farm, from engineering design, towards procurement, construction, installation, operations and disposal, i.e. such an approach also allows consideration of the main marine operations throughout the life of the wave energy project.

DTOceanPlus will, for the first time, develop and implement one set of digital models for components, sub-systems, devices and arrays. Standard data models will be adopted and adapted to represent Ocean Energy Systems. These models will offer a standard framework for the description of Ocean Energy Systems at different Technology Readiness Levels (TRLs) and levels of complexity.

Not only will these models provide the communication method between the various tools in the DTOceanPlus suite, but they will also provide a common language for the entire Ocean Energy sector and an architecture for storing project information. This common language will significantly enhance the ability of sector stakeholders to work collaboratively, thus accelerating development of the sector, whilst also further supporting stakeholders who wish to make objective comparisons between various technologies. The development of standard data format for Ocean Energy will significantly facilitate data and information exchange among various stakeholders.

The above needs were validated during the user consultation [1], in which respondents were asked about the usefulness of a Digital Representation for the next generation of ocean energy tools. They confirmed the importance of the Digital Representation to keeping track of the project development stages (from conceptual stage, to intermediate TRL technologies, and commercial phase), as well as managing the level of aggregation of the project (from the single component to a single device, or an array), and designing or evaluating several types of technologies.

2.2 EXPERIENCE FROM OTHER SECTORS

The Digital Representation of technology designs is becoming widespread in more mature engineering sectors to allow sharing of design information and testing of concepts in a virtual environment.

The traditional concept of engineering design focused on representing physical components is evolving to account for the whole product lifecycle, which also includes system processes and performance features. This is reflected by the increasing interest of companies in the implementation of Product Service System (PSS) approaches [6], as they are interested not only in delivering products, but also in providing through-life support for these products. This necessitates the integration of different tools for providing the required service. In order to develop an integrated PSS process, it is mandatory to build an "information architecture" through which the integration of different tools can be achieved. The technical implementation of PSS approaches has taken advantage of the digitalisation process [7]. Indeed, digitalisation not only helped in increasing the interactions between clients and provider, supporting the process of capturing the customer needs [8], but also became the infrastructural pathway towards the "servitization"[1] of engineering sectors, e.g. through the development of internet-of-things [9] and big data treatment [10]. As a matter of fact it can be concluded "the service revolution and the information revolution are two sides of the same coin" [11]. Moreover, the purpose of digitalisation will drive towards innovation and performance by allowing testing of concepts in a virtual environment.

[1] The servitization process is the gradual shift from product-centered value propositions to complex product-service systems offerings

Many sectors, in which servitization can assume an important role, have already taken advantage of digitalisation. For example, advanced manufacturing and "Industry 4.0" have benefited from the interaction with digitalisation, adding value to products, to processes and to managerial decisions [12]. However, the construction sector can be considered to be pioneering digitalisation, through the definition of the Building Information Modelling (BIM) framework. The BIM approach provides significant value throughout a project's life cycle [13]. This is supported through the use of digital objects, or digital twins, i.e. the Digital Representation of a physical asset (e.g. a building, a ship), and it can contain various digital models and collections of information and processes related to this object. The building industry shares the opinion that the use of digital twins is becoming a standard practice for construction projects [14].

In the maritime and energy fields, DNV GL [15] has recently stated that achieving data smart asset solutions could lead to improved business performance and better risk management. According to them, the digital twin approach is central to this next generation offering. Similarly, in the field of renewable energy, and in particular in wind energy, the Digital Representation of the system can help to increase its competitiveness, as it can allow asset condition and performance to be tracked dynamically. Therefore, international efforts currently focus on the Digital Representation of wind energy systems.

For example, the European Technology and Innovation Platform on Wind Energy (ETIP Wind) identified digitalisation as a key pathway towards cost reduction and system integration [16]. Among the attempts to achieve a holistic representation of wind energy systems suitable for digitalisation, the work developed within Task 37 (Systems Engineering) developed by the International Energy Agency (IEA) Wind is noteworthy. One of the objectives of IEA Wind Task 37 is to fully describe the ontology of a turbine (onshore and offshore) and associated plant.

Also Task 33 of IEA Wind, although with a different perspective (reliability and operation and maintenance), has tackled the issue of standardising the taxonomy of a wind plant [17]. It is important to use a common standard for operators and manufacturers of power plants. The German systems in wind energy, as Identification System for Power Plants (KKS, from the German *Kraftwerk-Kennzeichensystem*) and the Reference Designation System for Power Plants (RDS-PP) [18], for example, are a set of tools integrating the international codes.

Given the lack of a continuous streaming flux of operational data in the field of Ocean Energy Systems due to the early stage of development of Ocean Energy project, the static behaviour of the elements in the Digital Representation is reflected considering digital objects instead of digital twins. Such an integrated architecture should not only aim at representing the physical features of Ocean Energy Systems, but also facilitates the assessment of economic (e.g. lifetime costs) and technical (e.g. performance, energy yield, reliability and maintainability) impacts, as well as the social and environmental acceptance of such systems. In this way, Digital Representation will allow easier assessment of the readiness level of current technologies and as well as identification of criticalities, focusing on the innovation efforts.

2.3 A HOLISTIC APPROACH FOR THE DIGITAL REPRESENTATION

The framework for Digital Representation of Ocean Energy Systems responds to the objectives of DTOceanPlus and more generally to the needs of the sector as described above. As in the wind energy case, a digitalisation process in the field of ocean energy would accelerate integration of different subsystems, facilitate communication between various players, and yield data-driven designs and strategies to bring the cost of ocean energy down.

As with the overall DTOceanPlus project, the scope will cover the two more developed sources of ocean energy, namely tidal stream and wave energy. An effort has been made to reconcile and expand the approaches in [4] and [5].

According to user consultation results, the framework for building the Digital Representation could adopt the hierarchy of a **rooted tree structure**, accounting for all the functionalities to be covered in an Ocean Energy design. This approach is similar to the structure achieved in [5] for the capabilities and functions, but with a different scope in the present case. Such a structure will lead to a hierarchical set of relationships, representing the level of complexity of the project and the (de-)composition of the system into subsystems at different levels of details. A rooted tree data structure will also provide the means for the integration of different software packages.

After identifying the structure of the Digital Representation, a holistic approach is used in order to fill such a rooted tree structure with **digital objects**. Each object should have the same categories of attributes, for example, physical attributes, design (technical) attributes, process parameters, metrics, quantities and connectivity. Moreover, a rooted tree will allow hierarchical and/or topological relationships between object categories to be shown explicitly.

The need for a complete view of the system is the prime driver for achievement of a standard Digital Representation of Ocean Energy Systems. The transition from physical embodiment towards Digital Representation is made through the establishment of a data model defining the objects in the array, their topology (groupings), design datasets and attributes. Experience of previous projects and the first deployments was valuable in this process. Not only was it necessary to model the physical objects, but also to include the **marine operations** in the models. This allows continuous follow-up of the project through its entire lifetime as these activities can have a significant impact on the economic viability of ocean energy projects.

Therefore, the Digital Representation should not consist of functionalities as in [5] or be focused on technologies as in [4]. When analysing an ocean energy project, attention should be focused not only on physical system assets, but also on other important characteristics, such as the deployment site and the operational phases of the project lifecycle, from the subsystem installation to decommissioning. Moreover, the designer should be able to constrain from the **context** the potential design space to include some design options which are driven by the users, depending on financial aspects, technology choices or deployment-site related prerogatives that could impact design direction.

In order to achieve the targets of the Digital Representation, a set of high-level driving principles have been observed:

- Be flexible
- Be expandable/scalable
- Account for different levels of aggregation
- Enhance communication of technical information

These are discussed further in the following sub-sections.

2.3.1 BE FLEXIBLE

The flexibility of the Digital Representation should allow capture of the characteristics of Ocean Energy Systems for different levels of project complexity. This can be reflected in a flexible description of the object as a function of the TRL, or coarseness of the data.

Indeed, the Digital Representation should reproduce the characteristics of the system throughout all the project development phases, from the most conceptual ones, when a design is not fully established and several concepts are still under evaluation, to the most detailed phases of the design, when the amount of information is considerable and the technologies to be used have been selected.

The information stored at different levels of project maturity must be commensurate with the research, development and demonstration activity carried out at that stage, and vice versa. The DTOceanPlus project will generate a recommended set of stage activities that can produce the appropriate information, at the appropriate level of detail.

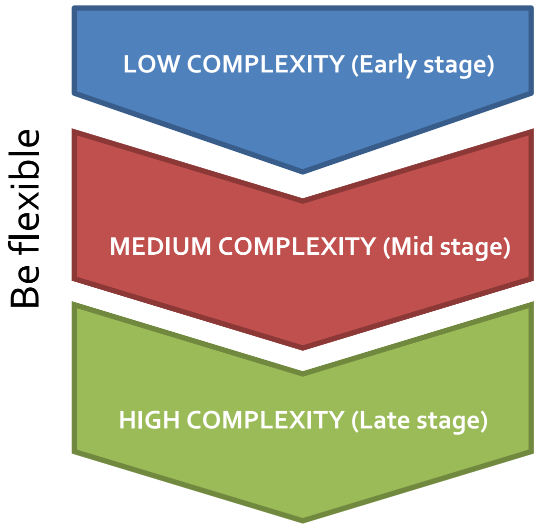

FIGURE 2-1: FLEXIBILITY

2.3.2 BE EXPANDABLE/SCALABLE

An important feature of the Digital Representation to avoid early obsolescence should be expandability and scalability.

As the ocean energy sector matures, lower levels of representation could be added, following the same "standards". Moreover, such an approach will permit continuous upgrade and maintenance of the digital objects. The introduction of new concepts, indeed, will be much easier in a well-established framework.

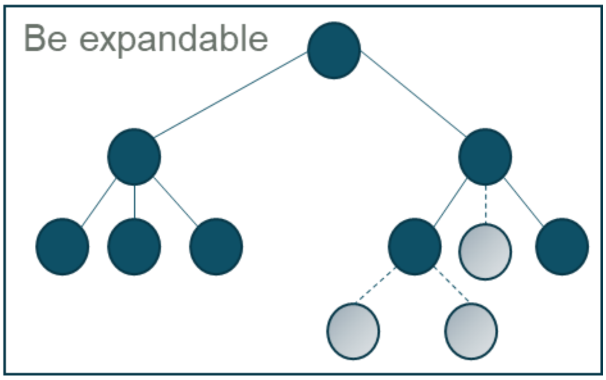

FIGURE 2-2: EXPANDABILITY

Such a structure could be expandable to a certain extent, supporting work at different levels of data granularity e.g. for lower TRLs with lacking technical information or for more mature technologies.

Ultimately, the Digital Representation framework herein developed and based on digital objects, should be easily expanded towards the inclusion of fully functional digital twins, fed by operational data if available.

2.3.3 ACCOUNT FOR DIFFERENT LEVELS OF AGGREGATION

The Digital Representation should also keep account of system performance (estimated by the DTOceanPlus toolset or any other software) at different levels of aggregation, thus opening the way to assessing the behaviour of a single device or subsystems and benchmarking them against various technologies, using a common base framework.

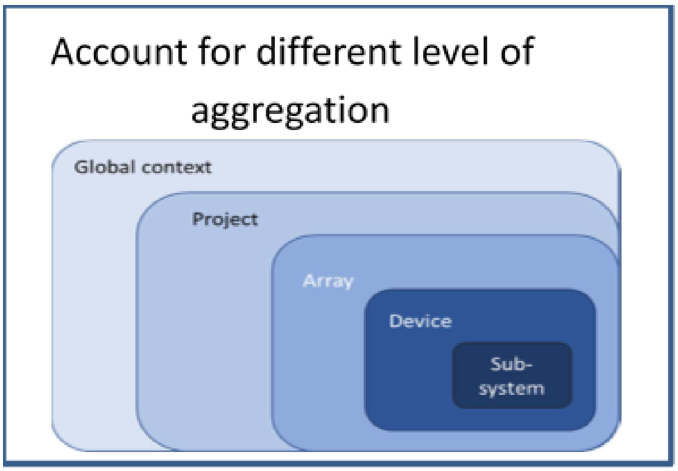

FIGURE 2-3: DIFFERENT LEVELS OF AGGREGATION

2.3.4 ENHANCE COMMUNICATION OF TECHNICAL INFORMATION

The last aspect of a Digital Representation framework to be considered is **standardisation** in order to help the development of the sector. This aspect could be seen from a double perspective.

From a more technical point of view, the Digital Representation is going to work as the base interface and "common language" making easier the exchange of data and communication among software. Therefore, the Digital Representation for Ocean Energy Systems is a common framework for transferring information among tools, not only those developed within the DTOceanPlus toolset, but also with other commercial alternatives, or other open sources modules, as well as in-house solutions.

From a more semantic perspective, a standardised Digital Representation framework "universally acknowledged" will constitute the base for developing a common understanding among different stakeholders of the ocean energy sector. By doing so, not only will the communication be de-risked and made seamless, but also the decomposition of an Ocean Energy System could be more easily understood. This requirement of the Digital Representation strongly combines with the requirement of standardisation of the sector. Only standardisation can capitalise on the lessons learnt in a project and ensure the outcomes of improved concepts, designs and operational planning can be further exploited.

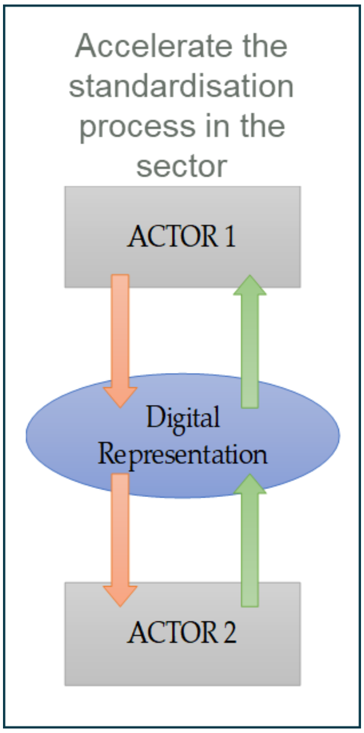

FIGURE 2-4: ENHANCED COMMUNICATION

The need to guarantee a smooth, robust and fast data flow among software developed by different developers represents a challenging benchmark for the Digital Representation and its aim to become a milestone in the definition of a common language and an interface for integrating external commercial tools. Indeed, through a robust and community-acknowledged Digital Representation scheme, the Digital Representation may take on the role of common interface when more than two tools must interact. More ambitiously, the Digital Representation aims at becoming a common data sharing structure not only among tools, but any kind of actor (i.e. user, software, stakeholder) in general.

3. THE DIGITAL REPRESENTATION FOR OCEAN ENERGY SYSTEMS

3.1 STRUCTURE OF THE DIGITAL REPRESENTATION AND GENERAL DEFINITIONS

An Ocean Energy System is characterised by an intrinsic complexity in terms of its architecture. Indeed, the number of different sub-systems, components, and the interactions among them, as well as the interaction with external environmental and context factors and a process domain for the deployment and maintenance of the system, makes the description of the system particularly challenging. Indeed, a representation able to fully capture not only the constitutive elements, at different levels of aggregation, but also the interactions among them is highly complex and subject to the risk of lack of completeness or consistency.

The major novelty of the Digital Representation developed in DTOceanPlus is that it not only includes elements of the "physical domain" [19] but also elements of the "process domain" and "performance and assessments" as a substantial parts of an ocean energy project, as well as context elements that lie outside the system but that inevitably affect the design. The physical domain elements respond to a "working principle" [20], i.e. a set of geometrical, physical, material related properties for the development of a function. Physical elements and processes are interrelated (connectivity) and both can significantly affect the viability of an ocean energy project. A schematic sketch of the design process of an Ocean Energy System, which is object of the representation, is reported Figure 3-1 inspired by [19].

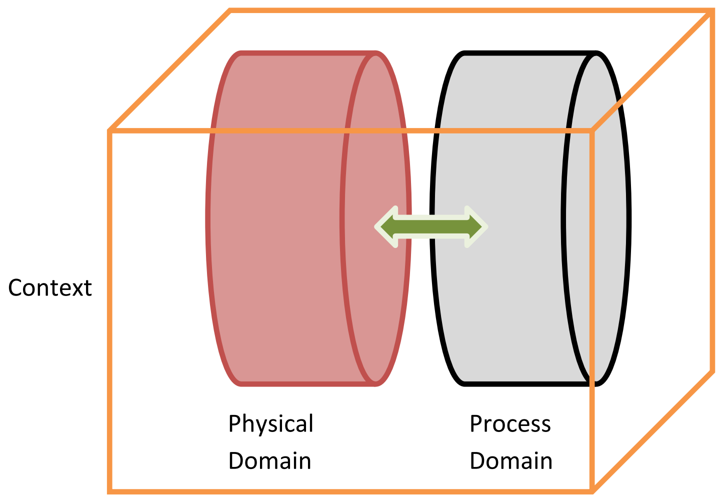

FIGURE 3-1: REPRESENTATION OF THE DOMAINS OF THE DESIGN OF AN OCEAN ENERGY SYSTEM

The design solution in the physical domain, related to the technologies adopted for the ocean energy system design, and the process domain, related to the different lifecycle phases and operations, are included in a context, i.e. a set of environmental and circumstantial conditions affecting the design. The main difference with [19] is that in [19] the requirements of the different domains are identified, including the user requirements and the functional ones. In this case, the representation in Figure 3-1 deals with the solution of the design, and for this reason the bidirectional arrow shows the interaction of the Physical Domain and the Process Domain while the whole design (i.e. the integration of both domains) is immersed in a context, i.e. the deployment site and other constraints.

By way of example, let us initially consider the physical domain of an ocean energy project, i.e. let us focus only on the Technology Design of the project. For the sake of simplicity, let us assume the final design of this project consists of three floating wave energy devices. The full design will comprise:

- One umbilical cable for each device
- The devices will be connected in series; thus, two intra-array cables are needed,
- Only a collection point and one export cable are considered
- Each device is connected with three individual mooring lines, comprising one station keeping system.

The representation of such a system could be seen in Figure 3-2.

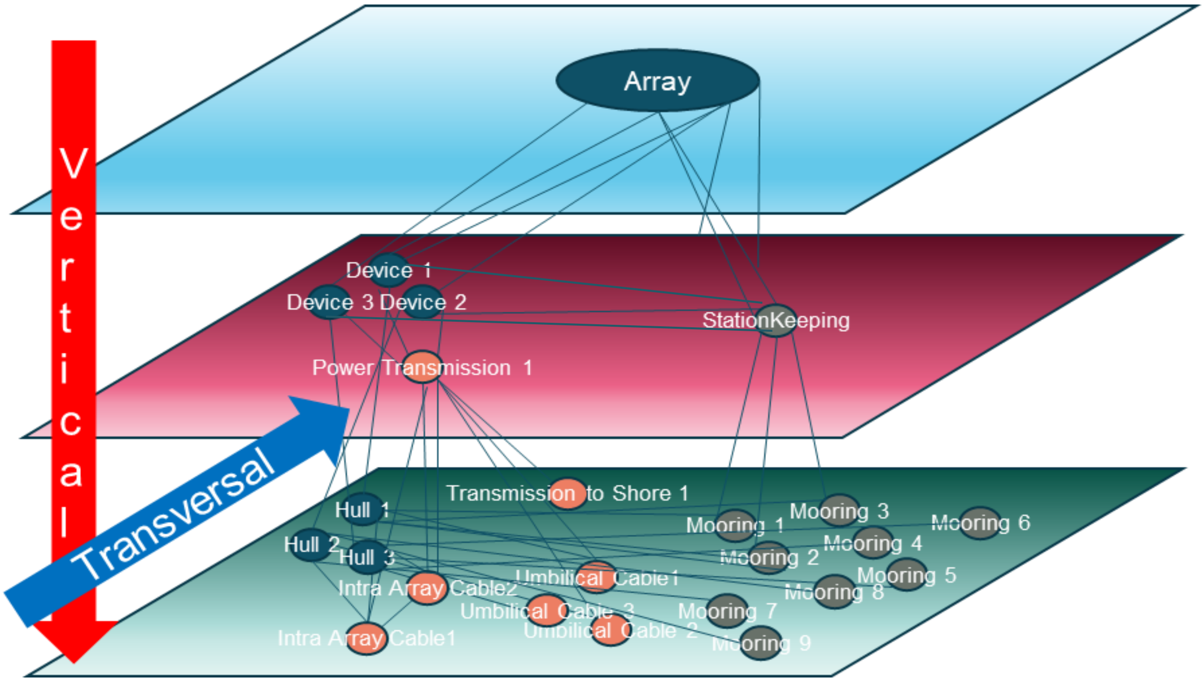

FIGURE 3-2: INCOMPLETE EXAMPLE OF OCEAN ENERGY SYSTEM (FOCUSED ON TECHNOLOGY)

First of all, a **vertical and hierarchical** dimension can be seen in this representation. An ocean energy project can be decomposed into different objects (in the following named “Families”), and again each family can be decomposed in “Groups” at its turn, and each group can be further decomposed into smaller, but more detailed components, until reaching a level of detail at which the component cannot be further decomposed. The connection in this vertical direction of the digital representation is mostly due to hierarchical and topological connection, and a “tree” based approach, therefore, seems to be particularly adequate for capturing the main features of the system. At this stage, it is however important to note that in such representation not only the physical components corresponding to the technological design should be represented, but also context elements (as the environment) and functional (as the operations) should find their own position in the representation.

This view of the structure of the digital representation is described in Section 0.

On the other hand, when describing the actual elements in the array, the interactions among different components, subsystems, groups and families should be accounted for. Such a **transversal view** of the digital representation will add to the topological connections among components the logical connection among the physical (technology) and the process (operations) domain and with the external environment. Each object in the digital representation will be represented by a blueprint, i.e. a common structure characterising the digital objects. Such a blueprint consists of an identifier of the object, some constitutive data (attributes) and all the connection above mentioned. The approaches for accounting these connections and the templates for the objects in the families are described in Section 3.3, while the full list of attributes for each object is reported in the Appendix.

The digital representation for Ocean Energy Systems developed in DTOceanPlus has been focused in developing a representation of the context, i.e. the **Environment**, of the physical domain, i.e. the **Technology Design**, and the Process domain, i.e. the **Phases** of an ocean energy system.

Accompanying the Digital Representation will be supporting information, such as site bathymetry and resource data, but these will not be part of the digital representation itself. It is important to notice that the digital representation is **self-contained**, i.e. all the basic information of the design is contained within the framework of the representation. For "off-the-shelf" components, such as cables or transformers, the relevant details will be stored as a dictionary within the relevant node of the Digital Representation, as shown in Table 3.1.

TABLE 3.1: EXAMPLE DICTIONARY OF OFF-THE-SHELF COMPONENT PROPERTIES

Key	Value
Manufacturer	Name
Manufacturer's reference	Ref Code
Key property 1	Value1
Key Property 2	Value2
…	…

3.2 THE "VERTICAL" DIMENSION OF THE DIGITAL REPRESENTATION

As described in Section 3.1, the digitalisation of the Ocean Energy Systems can take advantage of a tree structure to describe the hierarchical relationships between different elements in an ocean energy project. The shape assumed by a rooted tree is like the one in Figure 3-3.

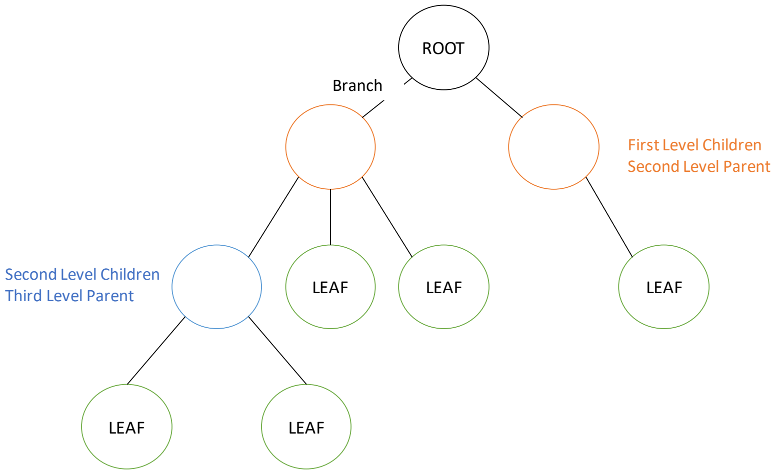

FIGURE 3-3: SCHEMATIC VIEW OF THE ROOTED TREE APPROACH.

The elements in a tree are:

The root node: this represents the initial node of the tree, or the top of the hierarchy. It acts also as a parent, as the following levels will depart from the root through branches. The root node in the Digital Representation of Ocean Energy Systems is "the project".

Parent-child nodes: depending on the user viewpoint, these are the nodes from which other branches depart (in this case, they act as parents) or connect to an upper level (in this case they act as *children*). The first parent is the root, and so on. The first level *children* are directly connected through branches to the root, and they represent the first level of detail of the system. In DTOceanPlus, the first level nodes are defined as "*families*" and the second level of nodes are "*groups*". Of course, each family should be defined in order to have a full definition of the project and each group could be furtherly broken down into more sub-groups with further level of detail, according to the requirements and needs of the user.

Leaf nodes: these are nodes, *children*, from which no other branch will depart. They represent the lowest level of detail in an ocean energy project.

The customisation of the rooted tree for Ocean Energy Systems, as obtained from the task in DTOceanPlus, is reported in Figure 3-4 and discussed in the following sections.

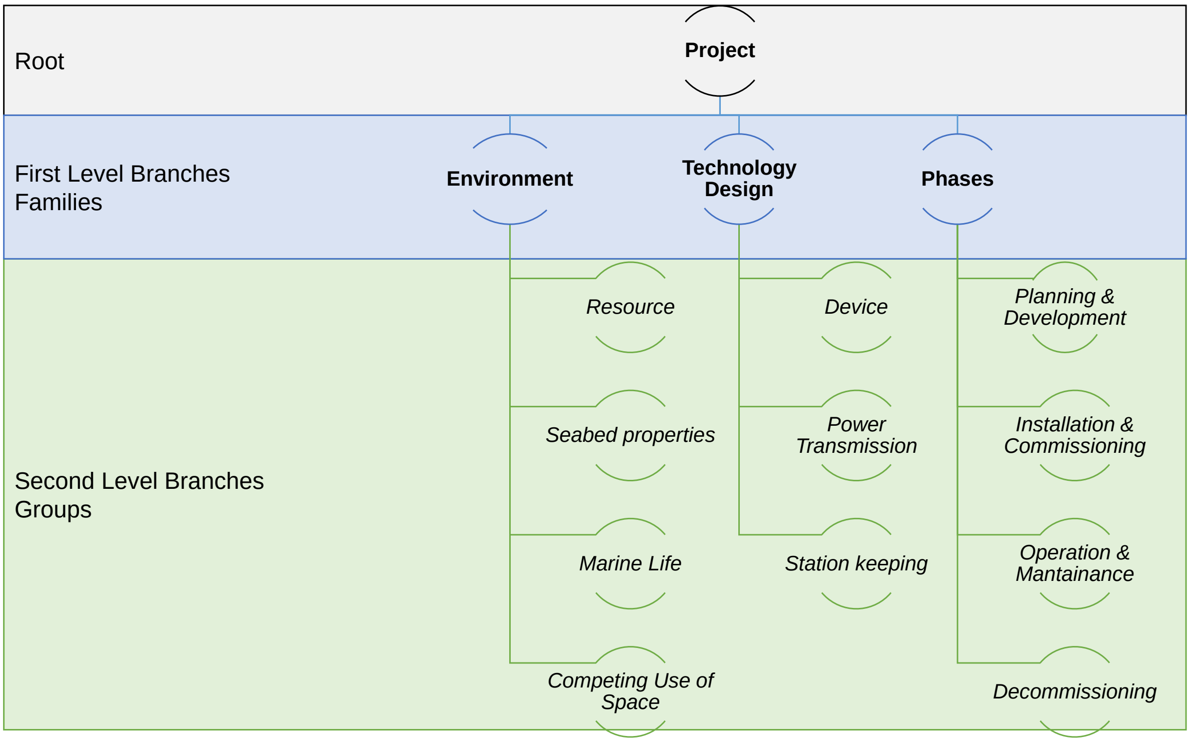

FIGURE 3-4: DIGITAL REPRESENTATION OF AN OCEAN ENERGY SYSTEM

3.2.1 THE ROOT: THE PROJECT

The root *class* of the Digital Representation is the "Project" (grey box and black in Figure 3-4). This represents the highest hierarchical level of an ocean energy project, collecting all the major information about the project and outcomes of the assessments. At this level, general information about the project and the technologies, the topology and other major characteristics, as well as the global assessment in terms of energy yield, reliability, economics, and environmental and social impacts will be collected. A project can be either a fully developed array or a single device. Moreover, at project level, a set of user options allows the definition of project context, such as financial information and project life, as well as other constraints and options that could drive the design direction (e.g. the choice of a specific topology for the electrical inter-array network, or mooring systems).

3.2.2 THE FIRST LEVEL BRANCHES: THE FAMILIES

The identified nodes and can be grouped in the following *families* (blue box and circles in Figure 3-4):

- ***Environment***: this *family* will compile all the data inherent to external factors, such as bathymetry, resource, marine life, as well as the competing use of the space, as a constraint of the project.
- ***Technology Design***: this *family* contains particularly varied information. It will contain information on the main subsystems of the Ocean Energy farm: Prime Mover, PTO & Control, Power Transmission and Station Keeping systems [3]. At this level, the information related to each

technology adopted in the project is collected, as well as information on their capital cost, efficiency in the power production chain, reliability and maintainability, or environmental impacts of the technologies.

- ***Phases***: This is the *family* in which the information about the processes in the project are represented, from Manufacturing to Decommissioning, passing through Installation and Service. Technical information on the logistics (selection of vessels, ports, personnel) as well as the phases of the project are compiled. Moreover, the impacts on operational expenditure are included, as well as environmental impacts during throughout the whole lifecycle of the project.

These *families* can be flexible, being represented as leaves at an early level of complexity or further expanded to second level branches (*groups*) for more detailed designs.

3.2.3 THE SECOND LEVEL BRANCHES: THE GROUPS

The *families* described in the above section will have several *children classes*, which have been named "*groups*". As any other object in the Digital Representation, each *group* will be characterised by a set of technical or technology related attributes, but also from partial assessments. In Figure 3-4the *groups* are contained in a blue box and blue circles.

3.2.3.1 The groups and sub-groups in the Environment Family

The diagram in Figure 3-5 shows the elements of the Environment Family in further detail.

The *groups* that are *children* of Environment are:

- **Resource**: in this *group*, all the information needed in terms of environmental conditions is stored, in terms of time series and statistics of waves, currents (which are resource) but also wind and sea levels that are used for the design of the project.
- **Seabed Properties**: in this *group*, the bathymetry of the lease area and the corridor area, as well as the soil properties are stored;
- **Marine Life**: in this *group*, the information about the probability of presence of receptors, as well as the initial conditions of the environment are stored;
- **Competing Use of Space**: the presence of pre-existing cabling, as well as vessel routes and no-go areas is stored here, being constraints for the project.

3.2.3.2 The groups in the Technology Design family

The Technology Design *family* is described in Figure 3-6. The higher-level object is the "array", i.e. the plant. The *children* of the Technology *family* include all the technology design related subsystems:

- **Device**: In this *group* all the information about the Prime Mover as well as the Power Take-Off (PTO) and Control System are stored. The information related to Prime Mover will include the functional structure of the devices, including the hydrodynamic characterization, as well as the structural components and the energy absorbed by each device. With respect to the Power Take-Off, it is classified for stage of the conversion (Mechanical conversion, Electrical Conversion and Grid Conditioning) and the Control System as Active, Reactive, Latching and User Defined
.

- **Power Transmission**, which includes the information about the design of the transmission to shore components, array network and collection point;
- **Station Keeping**, in which all the information about foundations and mooring systems, when applicable, is contained.

The *groups* and *sub-groups* included in the digital representation cover a wider range of possibilities with regard to the scope and capabilities of the DTOceanPlus toolset. For example, the tools in DTOceanPlus do not carry out any design of the Structural Components. However, in order to provide the digital representation with a wider scope, the possibility of including an object in terms of Structural Components has been considered in the final framework.

3.2.3.3 The Groups in the Phases family

As it could be seen in Figure 3-7, the Phases *family* has several *children*, in order to cover the whole lifecycle of the processes:

- **Planning & Development**: this *group* includes all the operations to be carried out before the commissioning of the plant. All the components and subsystems should be indeed designed, manufactured and tested. The information contained in this *group* exceeds the scope of DTOceanPlus toolset, but it has been included for future exploitation of the same framework.
- **Installation & Commissioning**: it includes all the operations needed to install the needed components of the plant and start the activities of the plant.
- **Operation & Maintenance**: the information contained this *group* is pertinent to all the operations and activities required to keep the Ocean Energy System operational during its lifetime;
- **Decommissioning**: the information contained in this *group* include the set of operations required to recycle and reuse the system, i.e. the last stage of the lifecycle of the plant.

It is important to highlight that the digital representation framework herein developed has been kept as general as possible, accounting for the future development of the sector and not only limited by the scope of the project.

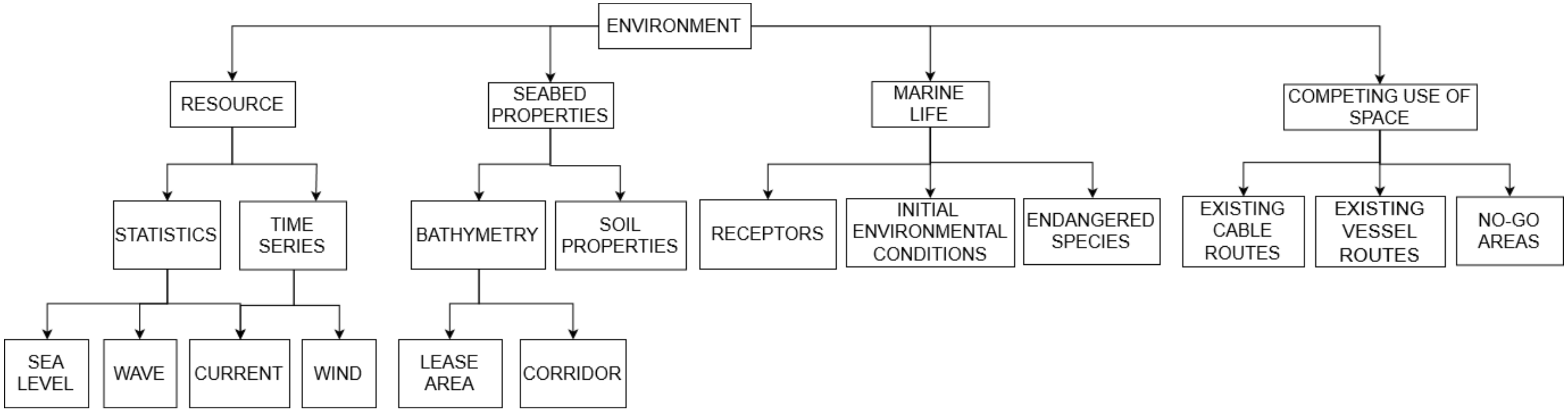

FIGURE 3-5: THE ENVIRONMENT FAMILY

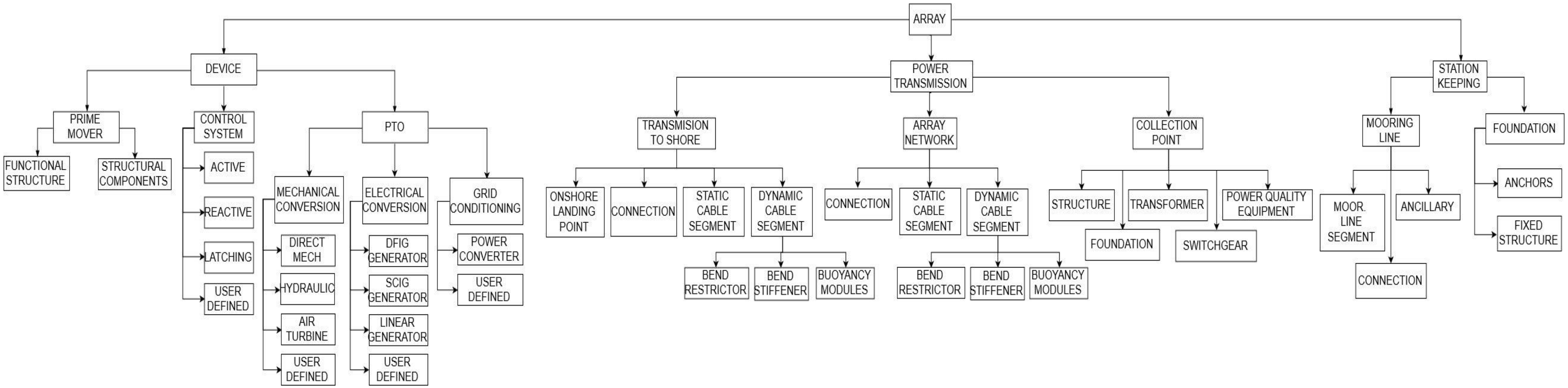

FIGURE 3-6: THE TECHNOLOGY DESIGN FAMILY

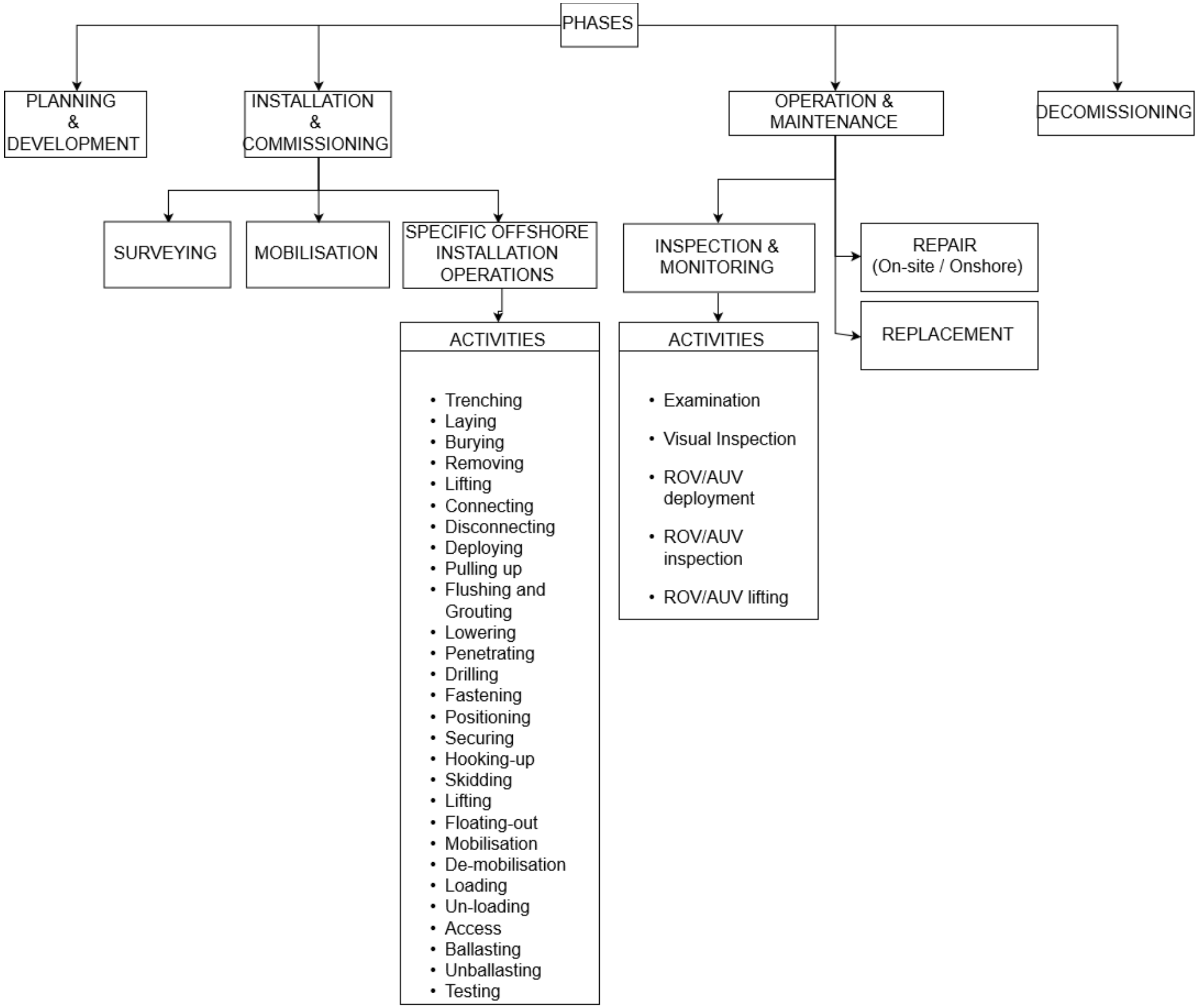

FIGURE 3-7: THE PHASES FAMILY

3.3 THE "TRANSVERSAL" DIMENSION OF THE DIGITAL REPRESENTATION

As noted in Section 3.1, it is important to account for an extra dimension of the representation: the actual instances of the objects. Let us consider Figure 3-8, which is as an extension of Figure 3-2, in which also the other families, corresponding to the other domains of the design, have been accounted for. It is evident that objects belonging to a family can interact with objects of the same family or group at a certain hierarchical level, as well as with objects belonging to other families. In this example, the operation of Decommissioning 1 interacts in the vertical direction with the Decommissioning Group, as it is a part of it. However, it also interacts with the Vessel Route 1, being a constraint of the Environmental Family, as well as with the Umbilical Cable 3, of the Technology design Family, being the technology to be dismantled. Therefore, it becomes apparent that, when dealing with the digital representation of a real ocean energy project, it is necessary to represent the single *instances*, i.e. the specific items of the representation.

This provides the Digital Representation with another dimension, which should be accounted for while considering its implementation. In order to identify each object, therefore, it is important to provide each item with a unique identifier, that allows the objects to be univocally defined within the framework of the representation.

Furthermore, it becomes important to identify the interactions between *instances* within the same family (mostly characterized by a hierarchical or topological relationship) and the relationships with the objects belonging to other families, which is, instead, simply relational.

During DTOceanPlus an effort was dedicated to find a common pattern for describing the objects in each family in order to keep the digital representation as generic as possible and account for its vertical and transversal dimensions.

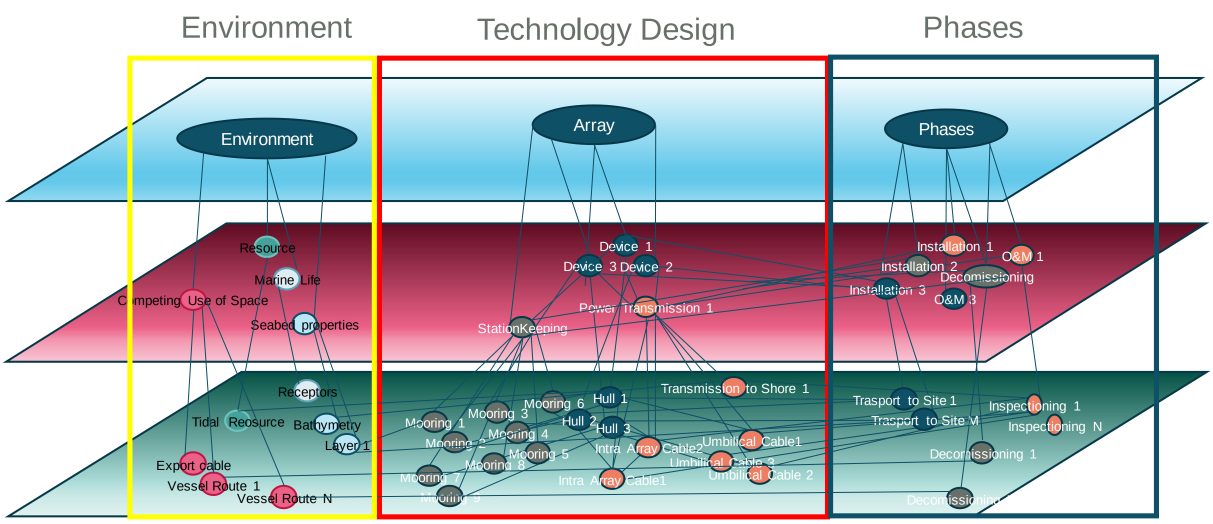

FIGURE 3-8: INCOMPLETE EXAMPLE OF OCEAN ENERGY SYSTEM (ACCOUNTING FOR ALL THE FAMILIES)

Given the different nature of the domains that Environment, Technology Design and Phases belong to, it was not possible to generalize completely the pattern of the data. As the elements in the Environment family are quite heterogeneous among them, the process of identifying a common pattern in the data structure could not be achieved, having each object or subset of object a specific structure. All the different structures for the objects in the Environment Family are included in Section 6.2. However, in the case of the Technology Design Family (Physical Domain) objects and the Phase (Process Domain) objects, the process of identifying common patterns was achieved and described in Sections 3.3.1 and 3.3.2 respectively.

3.3.1 OBJECTS IN THE TECHNOLOGY DESIGN FAMILY

Each instance of the Technology design family will be characterised by the same pattern in the structure of its description:

- **ID.** It is a unique identifier that allows to univocally identify an object of the Technology Design Family
- **Location.** It is a set of coordinates (x, y, z) in a given (local or global) coordinate system identifying a point representative for the element. Some objects will be identified by a couple of sets of coordinates, representing the initial and the final point of the object.
- **Physical and Functional properties.** They are specific for each object and dependent on the specific component/subsystem/system and the level of aggregation.
- **Assessments**. They represent the impact of the object in terms of performance, cost, reliability, environmental and social impact, they will depend on the level of aggregation and the specific component.
- **Hierarchical connection.** This field represents the connection with other objects of the Technology Design Family, i.e. these fields reflect the intra domain relationships. Generally, the field will include information about the group/family an object is part of and/or it is related with.
- **Connection** to other objects of the families, as Phases and Environment, i.e. these fields represent the inter-domain relationships. These connections, being only relational, are defined as lists of ID of the objects they are related to.

Despite the same pattern has been identified for the objects in the Technology Design Family, each object will require a customisation of the different attributes which are reported in Section6.

3.3.2 OBJECTS IN THE PHASES FAMILIES

Each instance of the Phases Family will be characterised by the same pattern in the structure of its description:

- **ID.** It is a unique identifier that allows to univocally identify an object of the Phases Family
- **Start of the activity/duration.** It is a date identifying the beginning of the phase/operation/activity and its duration
- **Assessments**. They represent the impact of the object of the Phase family in terms of performances, costs, reliability, environmental and social impact, they will depend on the level of aggregation and the specific component.

- **Vertical connection.** This field represent the connection with other objects of the Phases Family. Generally, the field will include information about the group/family an object is part of and/or it is related with.
- **Connection** to objects of other families, as Technology Design and Environment. These connections, being only relational, are defined as lists of ID of the objects they are related to.

The full description of the Phases family, as well the specific list of attributes for the objects are reported in Section 6.4.

3.4 EXAMPLES OF THE DIGITAL REPRESENTATION

Some examples have been developed in order to show the capability of the Digital Representation to capture the main characteristics of the physical assets and processes associated with an ocean energy array, and the corresponding assessment activity.

3.4.1 PHYSICAL ASSET: INDUCTION GENERATOR

The first example (see Figure 3-9) shows different levels of detail for a physical asset in an ocean energy project.

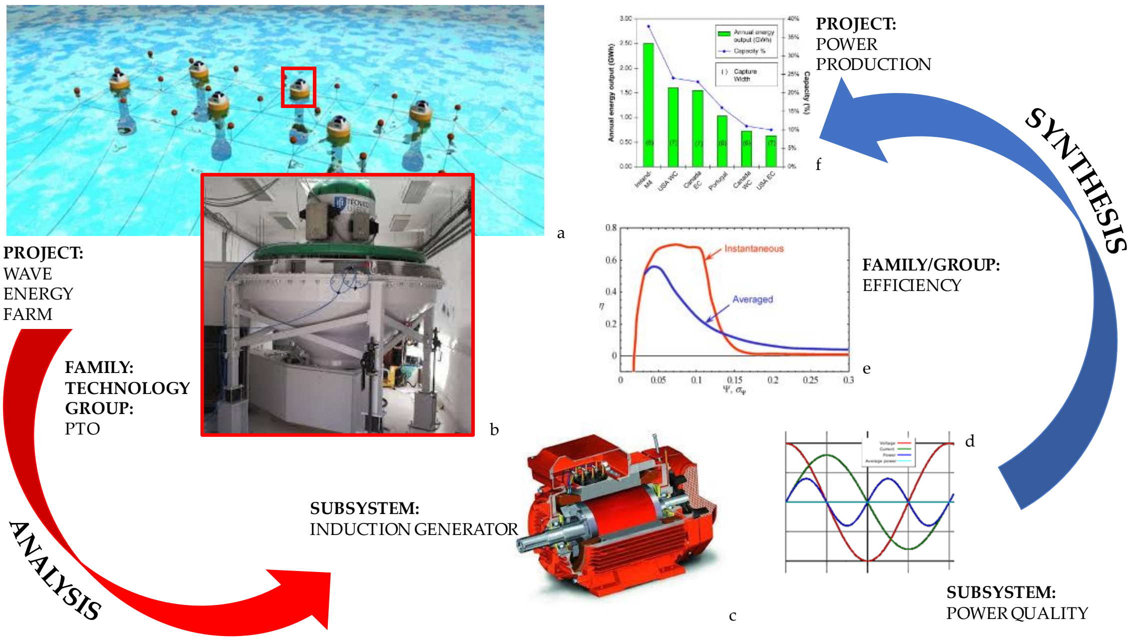

FIGURE 3-9: EXAMPLE OF DIGITAL REPRESENTATION OF A PHYSICAL ASSET (DESIGNING THE INDUCTION GENERATOR FOR THE PTO OF A WAVE ENERGY CONVERTER) AND ASSESSMENTS IN AN OCEAN ENERGY PROJECT. (IMAGES COURTESY: A & B [21]; C [24]; D [22]; E [23]; F [24])

On the upper left side of the figure, an array of wave energy converters is represented. This corresponds to the first hierarchical level of the wave energy project: the project. A set of attributes (see Table 3.2) describe the physical assets of this wave energy project.

As it has already been mentioned, the Digital Representation in DTOceanPlus can capture different levels of aggregation (i.e. array, device, sub-system). At the next level of the Digital Representation, the PTO system is analysed (see Table 3.3). This level of aggregation is also characterised by some attributes. The next level of increased detail describes other subsystems in the PTO, such as an induction generator, characterised by rated power and other properties, see Table 3.4. At any of these hierarchical levels assessment of key metrics can be carried out. These assessments are carried out using a synthetical approach to translate from assessments at more detailed sub-system level towards higher hierarchical levels for the estimation of global metrics.

TABLE 3.2: EXAMPLE PROJECT OBJECT FOR ARRAY OF WAVE ENERGY CONVERTERS FOR CASE STUDY IN FIGURE 3-9.

PROJECT	**ID**		Project 1	String
	LOCATION		EMEC	String
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Prime Mover Type	OWC	String
		Number of devices	5	String
		PTO Type	Air Turbine	String
		Number of PTOs per Device	2	Scalar
		Device Rated Power	500 kW	Scalar
		Array Rated Power	2.5 MW	Scalar
		Array Network	Radial	String
		Mooring System Type	CALM	String
		Number of Mooring Lines per Device	4	Scalar
		Foundation System Type	Drag Anchors	String
		Lifetime of the Project	20	Scalar
		Interest Rate	5%	Scalar
		Start of Installation	01/01/2020	Date
		Number of Operations per Year	2	Scalar
		Start of Service	01/06/2020	Date
		Start of Decommissioning	01/01/2040	Date
	ASSESSMENTS			
		LCOE	0.10 €	Scalar
		NPV	1e6 €	Scalar
		IRR	2.5 %	Scalar
		Energy Production per Year	10 GW	Scalar
		CAPEX	5e6 €	Scalar
		OPEX	7.5 e6 €	Scalar
		Downtime Hours per Year	100 hrs	List
		MTTF	1 e-4 hrs^{-1}	Scalar
		GWP: Global warming participation (CO_2 produced)	1e6	Scalar
		CED: Cumulative energy demand, (non-renewable energy used)	1e4	Scalar
		Number of jobs	1000	Scalar
		Overall Environmental Impact [negative/positive]	[-25/100]/[10/50]	Scalar

In this example, evaluation of system performance (i.e. one of the four assessments in DTOceanPlus) at the hierarchy level of the generator, can occur at various levels of detail. At the most detailed level power quality could be assessed; at a higher level, the efficiency of the PTO could be assessed; and finally all this information is condensed in the final value of the power production of the array.

TABLE 3.3: EXAMPLE PTO OBJECT FOR CASE STUDY IN FIGURE 3-9.

PTO	ID		PTO-1	**String**
	LOCATION	[x, y, z]	[0,0,0]; [0,0,2]	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Type of mechanical conversion	Air Turbine	string
		Number of PTO per device	2	Scalar
		Type of electrical conversion	SCIG Generators	String
		Type of grid conditioning	Power Converter	string
		Pnom	500 kW	scalar
		Name Material & weight	Steel & 500 kg	Array
	ASSESSMENTS			
		CAPEX	5e4 €	Scalar
		OPEX	1e5€	Scalar
		Failure rate	1e-4 hr-1	Scalar
		Risk priority number	-	Scalar
	HIERACHICAL CONNECTION			
		Part of {Device ID}	Device01	List of Strings
		Mechanical conversion {IDs}	Mech01	List of Strings
		Electrical Conversion {IDs}	Elec02	List of Strings
		Grid conditioning {IDs}	Grid04	List of Strings
	CONNECTION		-	
		Installation of PTO {Operation IDs}	[Inst01, Inst02, Inst03]	List of Strings
		O&M of PTO {Operation IDs}	[Op1, Op2, Op3]	List of Strings
		Decommissioning of PTO {Operation IDs}	[Dec1, Dec2]	List of Strings

TABLE 3.4: EXAMPLE SCIG GENERATOR FOR CASE STUDY IN FIGURE 3-9.

SCIG GENERATOR	ID		**SCG1**	**String**
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Pnom	250 kW	Scalar
		Name Material & weight	Steel & 10 kg	Array
	ASSESSMENTS			
		Efficiency	75%	Scalar
		Cost	1e3€	Scalar
		Failure rate	0.001	Scalar

	HIERACHICAL CONNECTION			
		Part of: {Elect. Conversion ID}	Eleco2	Scalar
	CONNECTION			
		Installation of Mech. Conv {Operation ID}	Inst1	String
		O&M of Mech. Conv {Operation ID}	Op1	String
		Decommissioning of Mech. Conv {Operation ID}	Dec2	String

3.4.2 PROCESS: INSTALLATION OF A MOORING LINE

Similarly, an example of the Digital Representation applied to a process is reported (see Figure 3-10).

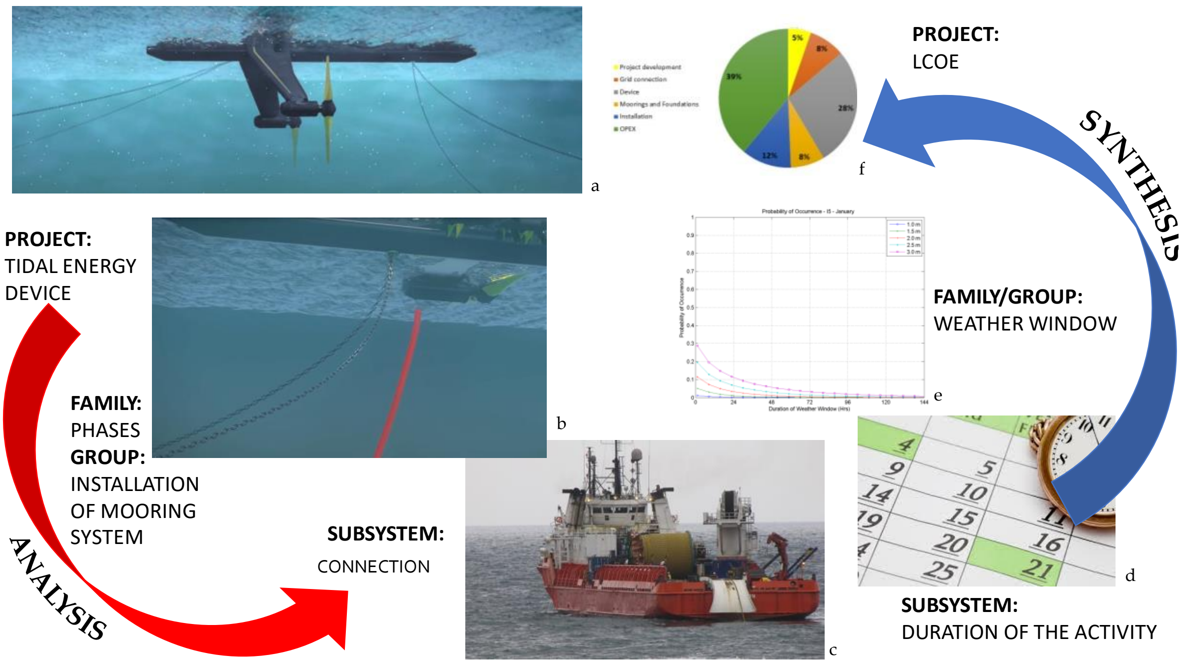

FIGURE 3-10: EXAMPLE OF DIGITAL REPRESENTATION OF A PROCESS (INSTALLATION OF A MOORING LINE) AND ASSESSMENTS IN AN OCEAN ENERGY PROJECT. (IMAGES COURTESY: A & B [25]; C [26]; D [27], E [28];F [29])

In this case, we are considering a single tidal energy device. However, the structure of the object Project would be totally similar to the one in Table 3.2. While entering into deeper detail, in this case, the installation of the mooring system for a one-device tidal project is considered (see Table 3.5). At this hierarchical level, the activities to be carried out, the operational limit conditions and some logistical requirement have been identified, see Table 3.6. When analysing the description of this process, the mooring systems hook-up is one of the activities to consider (See Table 3.6). It can be noticed that the fields in the description of the object, in case of the family Phases are exactly the same of the installation of the mooring line; the values are different as we are referring now only to one of the activities that are considered in the operations. Moreover, this activity is connected to the Operation INST-01, described by the object in Table 3.5. When these inputs are defined, the duration of the activity and its cost can be assessed. At a higher level, the duration of the whole operation (intended of a set of activities) will be obtained by considering all the activities involved; estimating the weather window occurrence will also allow measurement of the accessibility of the site. Finally, all this information will be used to generate the assessment at project level, for example the estimation of the Levelized Cost of Energy (LCoE).

As could be seen in Table 3.2, Table 3.5 and Table 3.6, it is crucial to establish the connectivity between the physical domain and the process domain, to associate each physical element with a set of processes and vice versa.

TABLE 3.5: EXAMPLE OF INSTALLATION OF MOORING LINE FOR DEVICE OF TIDAL ENERGY CONVERTERS

INSTALLATION	**ID**		INST-01	String
	NAME		Installation of Mooring System	String
	TYPE	Installation		String
	START/END			
		Start date	20/02/2020	Date
		End Date	28/02/2020	Date
	DURATION			
		Total Duration	168 h	Scalar
		Duration at Sea	100 h	Scalar
		Duration at Port	15 h	Scalar
		Waiting time	20 h	Scalar
		Mobilisation Time	33 h	Scalar
	VESSELS, PORTS, EQUIPMENT			
		Type of Vessel		String
		Number of Vessels	1	Scalar
		Port	Santander	String
		Other Equipment	-	String
		Operating Limiting Conditions [Hs, Tp, Vc, Vw]	[1.5,7, -, -]	List of scalars
	ASSESSMENTS			
		Downtime Hours [h]	-	Scalar
		Vessel/equipment consumption	25	Scalar
		Vessel Route [list of coordinates]	[0,0], [0,1], …, [125,345] ….	List of coordinates
		Operation cost	1e5 €	Scalar
		Production of CO2 and other pollutants	1e4	Scalar
		Number of crew/workers	10	Scalar
		Risk of Collision (in case of Vessel operation)	25/100	Scalar
		Underwater nois	24/100	Scalar
	CONNECTION WITH PHASE			

		Is Part of {Operation ID}	-	List of strings
	CONNECTION WITH TECHNOLOGY DESIGN			
		Technology (ies) involved	Moorign1-	List of strings
	CONNECTION WITH SITE			
		Id of the Time Series	TimeSeries1	List of strings

TABLE 3.6: EXAMPLE OF MOORING LINE CONNECTION FOR DEVICE OF TIDAL ENERGY CONVERTERS

CONNECTION	**ID**	HOOK-01	-	String
	NAME	Hook up of Mooring System	-	String
	TYPE	Hook up		String
	START/END			
		Start date	22/02/2020	Date
		End Date	22/02/2020	Date
	DURATION			
		Total Duration	8 h	Scalar
		Duration at Sea	8 h	Scalar
		Duration at Port	- h	Scalar
		Waiting time	- h	Scalar
		Mobilisation Time	- h	Scalar
	VESSELS, PORTS, EQUIPMENT			
		Type of Vessel		String
		Number of Vessels	1	Scalar
		Port	Santander	String
		Other Equipment	-	String
		Operating Limiting Conditions [Hs, Tp, Vc, Vw]	[1.5,7, -, -]	List of scalars
	ASSESSMENTS			
		Downtime Hours [h]		Scalar
		Vessel/equipment consumption		Scalar
		Vessel Route [list of coordinates]		List of coordinates
		Operation cost	1e5 €	Scalar
		Production of CO_2 and other pollutants	-	Scalar
		Number of crew/workers	10	Scalar
		Risk of Collision (in case of Vessel operation)	25/100	Scalar
		Underwater noise	24/100	Scalar
	CONNECTION WITH PHASE			
		Is Part of {Operation ID}	INST-01	List of strings
	CONNECTION WITH TECHNOLOGY DESIGN			
		Technology (ies) involved	Moorign1-	List of strings
	CONNECTION WITH SITE			
		Id of the Time Series	TimeSeries1	List of strings

The Digital Representation can capture the characteristics of the system at different stages of the project (i.e. early stage, mid stage or late stage), according to the level of information available, the TRL of the technology and the stage of development of the project (from conceptual stage to detailed engineering). This means that the framework of the Digital Representation can work throughout the project lifecycle and that the functions implemented in the tools, as well as the detail of the data required and the assessment to be computed, could vary accordingly.

3.5 THE REQUIREMENTS FOR IMPLEMENTATION OF THE DIGITAL REPRESENTATION: FILE FORMATS

The Digital Representation (DR) for Ocean Energy Systems aims at facilitating communication between different software components and stakeholders. This requires that widely accepted, standardised data formats are used in its implementation. Experience from other sectors, acceptance among potential users, the level of dissemination, flexibility of use, expandability and maintenance constitute some of the main drivers in the selection of the most appropriate solution. Several data formats are commonly used for data sharing, such as text based hierarchical data formats (e.g. HDF5) or mark-up language (e.g. XML), as well as non-mark-up options (e.g. YAML). These are taken under consideration along with other data formatting from BIM experience.

XML and JSON formats seem to be good candidate for the implementation of the DR of Ocean Energy System because they can be used with a schema (XSD or JSON schema) that can be used to enforce that a document is valid or not. They also have the advantage to be Human Readable and to have a lot of tool and libraries that can be used to read them. These formats are widely spread and used in many different types of application. For example, there is an XML version of IFC which is the exchange format for BIM. The schema can be versioned to follow the evolution of the Digital Representation to ensure it is compatible with the version used by an application when exporting/importing a project to another system.

It is also important to notice that the DR of Ocean Energy System, will be composed of one main file along with some reference files such as input files (like bathymetry) or result files produced by the different modules (e.g. mesh, simulation results, reports, etc.). These additional files will be kept in their own format, which are standard format for this kind of information (e.g. CSV, netcdf, pdf, etc.) The DR will just contain reference to these files. The reference files should be exported in a directory (or a directory structure) with the same name as the DR file.

Alternatively, it can be considered to define the DR format as an archive file that contains the main file and the reference files. The application can automatically extract the files when importing a DR, and pack them together when exporting to this format. A single file would have the advantage of avoiding any inconstancies if a reference file is missing. Nevertheless, it should be carefully considered due to the large size of these reference files (e.g. bathymetry, mesh), and because the unpack/pack process can be time consuming.

The DR of Ocean Energy System format could be called OES format, with the extension OES. Likewise, for a packed version, the extension could be called ZOES.

4. FURTHER WORK

Deliverable D7.1 has drawn the full architecture of the Digital Representation for Ocean Energy Systems, pointing out the requirements of the representation to cover the greatest number of stakeholder and ambitiously aiming at becoming a milestone towards the standardisation of the data model for sharing the information among different actors in the industry.

The description of the attributes in Section 6 (Annex) and the approach towards the implementation in Section 3.5 will be the basis upon which the digital representation will be built in practical terms, during the implementation of the different tools and modules of DTOceanPlus:

- **Structured Innovation Tool (SI)**, for concept creation, selection, and design: Task 3.2.
- **Stage Gate Tool (SG)**, using metrics to measure, assess and guide technology development: task 4.2.
- **Deployment Tools**, supporting optimal device and array deployment: Tasks T5.2-8.
  - Site Characterisation (SC);
  - Energy Capture (EC);
  - Energy Transformation (ET);
  - Energy Delivery (ED);
  - Station Keeping (SK);
  - Logistics and Marine Operations (LMO).
- **Assessment Tools**, to quantify key parameters: Tasks 6.2-6.
  - System Performance and Energy Yield (SPEY);
  - System Lifetime Costs (SLC);
  - System Reliability, Availability, Maintainability, Survivability (RAMS);
  - Environmental and Social Acceptance (ESA).

The Digital Representation for Ocean Energy Systems should be applied to the validation scenarios run during the activities of WP7 (T7.4 and T7.5).

The concept of the Digital Representation will be presented to stakeholder during a set of dissemination and training actions within the activities of WP9:

- Conference papers: at EWTEC 2019, the Digital Representation was presented for the first time in a public conference [30];
- Journal paper: it is expected that a journal paper, published open access during 2020 will describe the concept;
- A webinar, during winter 2019/2020, will serve to further disseminate the concept to interested stakeholder and collect their feedback in order to expand its implementation, if needed.

5. REFERENCES

[1] D. Noble and E. Medina-Lopez, 'Results from user-groups consultation', The University of Edinburgh, Deliverable 2.1 DTOceanPlus D2.1, 2018.
[2] US Department of Energy, 'WIND AND WATER POWER PROGRAM'. 2010.
[3] D. Ingram, G. Smith, C. Bittencourt-Ferreira, and H. Smith, *Protocols for the Equitable Assessment of Marine Energy Converters*. The University of Edinburgh, School of Engineering, 2011.
[4] B. Hamdni, C. Mathieu, and C. Bittencourt, 'Generic WEC System Breakdown', DNV-GL, Delverable 5.1 SDWED 5.1, 2014.
[5] D. Bull *et al.*, 'Systems engineering applied to the development of a wave energy farm', *Prog. Renew. Energ. Offshore G Soares Ed Lisbon Port. Taylor Francis Group Lond.*, pp. 189–196, 2016.
[6] A. McKay and S. Kundu, 'A representation scheme for digital product service system definitions', *Adv. Eng. Inform.*, vol. 28, no. 4, pp. 479–498, Oct. 2014.
[7] W. Coreynen, P. Matthyssens, and W. Van Bockhaven, 'Boosting servitization through digitization: Pathways and dynamic resource configurations for manufacturers', *Ind. Mark. Manag.*, vol. 60, pp. 42–53, Jan. 2017.
[8] D. Gago and L. Rubalcaba, 'Innovation and ICT in service firms: towards a multidimensional approach for impact assessment', *J. Evol. Econ.*, vol. 17, no. 1, pp. 25–44, Feb. 2007.
[9] A. Rymaszewska, P. Helo, and A. Gunasekaran, 'IoT powered servitization of manufacturing – an exploratory case study', *Int. J. Prod. Econ.*, vol. 192, pp. 92–105, Oct. 2017.
[10] D. Opresnik and M. Taisch, 'The value of Big Data in servitization', *Int. J. Prod. Econ.*, vol. 165, pp. 174–184, Jul. 2015.
[11] R. T. Rust and M.-H. Huang, 'The Service Revolution and the Transformation of Marketing Science', *Mark. Sci.*, vol. 33, no. 2, pp. 206–221, Jan. 2014.
[12] T. Paschou, F. Adrodegari, M. Perona, and N. Saccani, 'Digital servitization in manufacturing as a new stream of research: a review and a further researc', in *Chapters*, Edward Elgar Publishing, 2018, pp. 148–165.
[13] B. Hardin, *BIM and construction management: proven tools, methods, and workflows*. Indianapolis, Ind.: Wiley, 2015.
[14] Siemens, 'Three perspectives on digital twins'. [Online]. Available: https://www.siemens.com/customer-magazine/en/home/buildings/three-perspectives-on-digital-twins.html. [Accessed: 22-Jun-2018].
[15] Ø. Smogeli, 'Digital twins at work in maritime and energy', DNV-GL, 2016.
[16] ETIP Wind, 'When wind goes digital'. ETIPWind, 2017.
[17] B. Hahn *et al.*, 'Recommended practices for wind farm data collection and reliability assessment for O&M optimization', *Energy Procedia*, vol. 137, pp. 358–365, 2017.
[18] J. Richnow, C. Rossi, and H. Wank, 'Designation of wind power plants with the Reference Designation System for Power Plants-RDS-PP', *VGB PowerTech*, vol. 94, no. 7, 2014.
[19] N. P. Suh, *Complexity: Theory and Applications.* N. Y., USA: Oxford University Press, 2005.
[20] G. Pahl, W. Beitz, J. Feldhusen, and K.-H. Grote, *Engineering Design: A Systematic Approach*, 3rd ed. London: Springer-Verlag, 2007.
[21] 'Home - OPERA H2020'. [Online]. Available: http://opera-h2020.eu/. [Accessed: 13-Oct-2019].
[22] 'Power Factor Correction', *Electrocorder*. [Online]. Available: https://electrocorder.com/blogs/news/power-factor-correction. [Accessed: 13-Oct-2019].
[23] A. Falcão, 'Wave energy utilization: A review of the technologies', *Renew. Sustain. Energy Rev.*, vol. 14, no. 3, pp. 899–918, 2010.
[24] 'Energy and the Environment-A Coastal Perspective -'. [Online]. Available: http://coastalenergyandenvironment.web.unc.edu/. [Accessed: 13-Oct-2019].

[25] 'FloTEC: Floating Tidal Energy Commercialisation', *FloTEC*. [Online]. Available: https://orbitalmarine.com/flotec/. [Accessed: 13-Oct-2019].
[26] R. Ltd, 'Opera sings for Global Maritime', *reNEWS - Renewable Energy News*, 15-Jun-2016. [Online]. Available: https://renews.biz/42240/opera-sings-for-global-maritime/. [Accessed: 13-Oct-2019].
[27] 'Methods to estimate task and activity duration - Planning Engineer'. [Online]. Available: https://planningengineer.net/methods-estimate-task-activity-duration/. [Accessed: 13-Oct-2019].
[28] C. Maisondieu and L. Johanning, 'Best practice report - Installation procedures. Deliverable 3.6.2 from the MERiFIC Project', Mar. 2014.
[29] 'International Levelised Cost Of Energy for Ocean Energy Technologies', Ocean Energy Systems (OES).
[30] V. Nava, P. Ruiz-Minguela, and J. Hodges, 'A novel framework for the Digital Representation of physical and functional characteristics of Ocean Energy Systems', p. 10.

6. ANNEX: DATA STRUCTURES FOR THE DIGITAL REPRESENTATION

In the following, the structure and objects of the Digital Representation have been broken down and their attributes have been described, defining the format agreed with the partners at time of writing (September 2019). The actual implementation of the Digital Representation could slightly change, depending on issues that could be raised at the development and validation stage as well as the feedback from the dissemination and training activities. If any, modifications will be reported in the user manual of the DTOceanPlus tools.

6.1 THE PROJECT

The Project object represents the highest level of aggregation and the fields describing it are in Table 6.1.

TABLE 6.1: THE PROJECT OBJECT

PROJECT	**ID**		-	String
	LOCATION			String
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Prime Mover Type	-	String
		Number of devices	-	String
		PTO Type	-	String
		Number of PTOs per Device	-	Scalar
		Device Rated Power	kW	Scalar
		Array Rated Power	kW	Scalar
		Array Network	-	String
		Mooring System Type	-	String
		Number of Mooring Lines per Device	-	Scalar
		Foundation System Type	-	String
		Lifetime of the Project	-	Scalar
		Interest Rate	-	Scalar
		Start of Installation	-	Date
		Number of Operations per Year	-	Scalar
		Start of Service	-	Date
		Start of Decommissioning	-	Date
	ASSESSMENTS			
		LCOE	€	Scalar
		NPV	€	Scalar
		IRR	€	Scalar
		Energy Production per Year	kWh	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Downtime Hours per Year	hrs	List

		MTTF	hrs^{-1}	Scalar
		GWP: Global warming potential (CO_2 produced)	-	Scalar
		CED: Cumulative energy demand, (non-renewable energy used)	-	Scalar
		Number of jobs	-	Scalar
		Overall Environmental Impact [negative/positive]	-	Scalar

6.2 ENVIRONMENT FAMILY

The Environmental Family collects a set of heterogeneous information about the environmental conditions of the lease area and the export cable zone in which the ocean energy project is deployed. The tree of the Environment Family is shown in Figure 3-5. Some of the information is taken from catalogues (green cells), while the purple cells reflect the outcome of design.

6.2.1 THE RESOURCE

In the Resource group (see Figure 6-1), the information pertinent to the time series and statistics of the sea level, wave conditions, current and wind are considered. The importance of the resource Group is not only in terms of energy yield, but also used in the Deployment Design tools as external excitation for the design of the technologies.

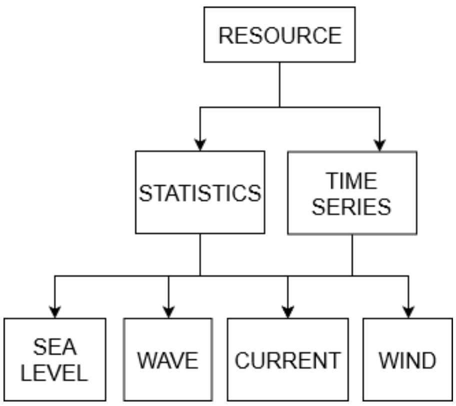

FIGURE 6-1: FAMILY ENVIRONMENT, GROUP RESOURCE

Table 6.2 recompile the main information about Time series and Statistics for this group. All the timeseries will be two-columns tables:

- the first column will be the time-id
- the second column will comprise the variables reported in Table 6.2.

Similarly, the statistics will be tables, one for each variable in Table 6.2.:

- The first value will be an ID, identifying the sea state, the current/wind/water level condition,

- The second value will be the variable in Table 6.2.

TABLE 6.2: TIME SERIES AND STATISTICS FOR THE RESOURCE GROUP

		Quantity	Units
WAVES	TIMESERIES	Hs (significant wave height)	M
		Tp (wave peak period)	S
		dp (wave peak direction, coming from)	Deg
		te (wave energy period)	S
		gamma (JONSWAP peak shape parameter)	-
		CgE (wave energy flux)	kW/m
	STATISTICS	Hs mean	m
		Hs min	m
		Hs max	m
		Tp mean	s
		Tp min	s
		Tp max	s
		CgE mean	kW/m
		CgE min	kW/m
		CgE max	kW/m
		gamma mean	
		gamma min	
		gamma max	
		EPD Hs (Empirical Probability Distribution)	
		monthly-EPD Hs (Empirical Probability Distribution)	
		EJPD Hs/Tp (Empirical Joint Probability Distribution)	
		monthly-EJPD Hs/Tp (Empirical Joint Probability Distribution)	
		EJPD Hs/dp (Empirical Joint Probability Distribution)	
		monthly-EJPDH/dp (Empirical Joint Probability Distribution)	
		EJPD3v Hs/dp/Tp (Empirical Joint Probability Distribution with 3 variables)	
		EXT Hs (extreme return values)	m
		EXT Tp (extreme return values)	S
		wave extreme contours Hs/Tp	-
CURRENTS	TIMESERIES	mag (current velocity)	m/s
		theta (current direction, going to)	deg
		U (current zonal velocity)	m/s
		V (current meridional velocity)	m/s
		Cp (current available power)	kW/m^2
	STATISTICS	mag mean	m/s
		mag min	m/s

		mag max	m/s
		Flux mean	kW/m^2
		Flux min	kW/m^2
		Flux max	kW/m^2
		EPD mag (Empirical Probability Distribution)	
		monthly-EPD mag (Empirical Probability Distribution)	
		EPD theta (Empirical Probability Distribution)	
		monthly-EPD theta (Empirical Probability Distribution)	
		EJPD mag/theta (Empirical Joint Probability Distribution)	
		monthly-EJPD mag/theta (Empirical Joint Probability Distribution)	
		EXT mag (extreme return values)	
		Current profile	
WIND	**TIME SERIES**	mag10 (10m-wind velocity)	m/g
		theta10 (10m-wind direction, coming from)	Deg
		U10 (10m-wind zonal velocity)	m/s
		V10 (10m-wind meridional velocity)	m/s
		gust10 (10m-wind gusts)	m/s
	STATISTICS	mag10 mean	m/s
		mag10 min	m/s
		m/smag10 max	
		EPD mag10 (Empirical Probability Distribution)	
		monthly-EPD mag10 (Empirical Probability Distribution)	
		EPD theta10 (Empirical Probability Distribution)	
		monthly-EPD theta10 (Empirical Probability Distribution)	
		EJPD mag10/theta10 (Empirical Joint Probability Distribution)	
		monthly-EJPD mag10/theta10 (Empirical Joint Probability Distribution)	
		EXT mag10 (extreme return values)	
		EXT gust10 (extreme return values)	
SEA LEVEL	**TIMESERIES**	XE (water surface fluctuation, relative to MSL)	m
		WLEV (water level, relative to bottom => XE + bathymetry)	m
	STATISTICS	WLEV mean	m
		WLEV min	m
		WLEV max	m

		EPD WLEV (Empirical Probability Distribution)	
		monthly-EPD WLEV (Empirical Probability Distribution)	
		EXT WLEVnegative (extreme return values)	
		EXT WLEVpositive (extreme return values)	

6.2.2 SEABED PROPERTIES

Seabed Properties include both the bathymetry (lease area and corridor layer) and the type of soil of the seabed (see Figure 6-2)

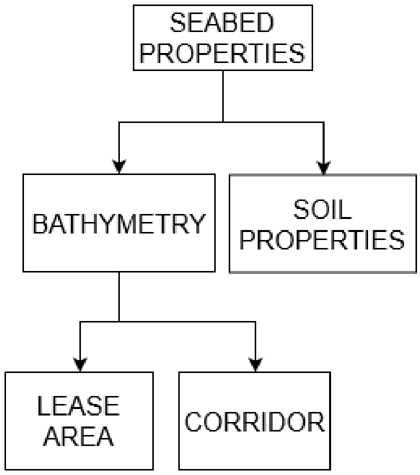

FIGURE 6-2: FAMILY ENVIRONMENT, GROUP SEABED PROPERTIES

The Bathymetry of the lease area and of the corridor (i.e. the area around the positioning of the export cable) will be tables, characterised by:

- an ID
- a set of coordinates (a couple of UTM coordinates defining the spatial position of the nodes and the depth).

Mechanical and physical properties will be either provided by the user or default values. Data will be summarized in a table with the following information:

- ID pointing at the bathymetry
- Soil type/classification
- Soil submerged density
- Undrained cohesion
- Effective friction angle
- Layer thickness
- Distance to rock bed

6.2.3 MARINE LIFE

Marine Life includes information about environmental receptors, probability of presence of endangered species, and the initial conditions of the environment in which the project will be deployed.

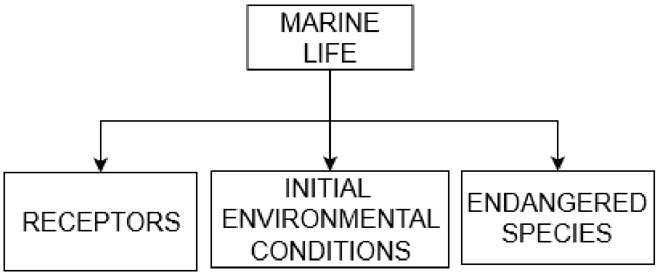

FIGURE 6-3: FAMILY ENVIRONMENT, GROUP MARINE LIFE

The table of the receptors will consist of a two-column table:

- The first column the name of the receptor (e.g. Medium diving birds, Shallow diving birds, Large odontocete, Mysticete, etc.)
- The second column will be the probability of presence of this receptor.

The initial environmental condition table will consist in a table with two columns:

- The first column will be the name of the "parameter", e.g. initial electrical field, magnetic field, initial temperature, etc...
- The second column will be the value of the parameter in column 1.

The table of endangered species will consist of a four-column table:

- The first column will be the common name of the species
- The second column will be the Latin name of the species
- The third column will be the status of the species as classified by *International Union for the Conservation of Nature and Natural Resources* (IUCN)
- And the fourth, the probability of presence in the area

6.2.4 COMPETING USE OF SPACE

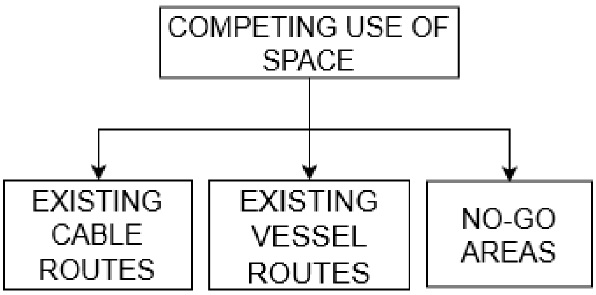

FIGURE 6-4: FAMILY ENVIRONMENT, GROUP COMPETING USES OF SPACE.

The Competing Use of Space family (see Figure 6-4) will consist in a set of "constraints" given by the presence of existing cable routes, or vessel routes or no-go areas that will be identified during the design.

All the tables will be characterised by three columns:

- A Route/No-Go area ID, identifying the route/No-go area
- An ID, ordering the points of the route/no-go area
- A couple (x, y) of coordinates, corresponding to the UTM coordinates of the point considered.

6.3 TECHNOLOGY DESIGN FAMILY

Figure 3-6 represents the object at the highest level of aggregation, which in this case is represented by the "Array".

The description of the "Array" is reported in Table 6.3.

TABLE 6.3: THE ARRAY OBJECT

ARRAY	**ID**		-	String
	LOCATION			String
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Prime Mover Type	-	String
		Number of devices	-	String
		PTO Type	-	String
		Number of PTOs per Device	-	Scalar
		Device Rated Power	kW	Scalar
		Array Rated Power	kW	Scalar
		Array topology type (direct, star, radial, loop, hybrid)	-	String
		Array Hierarchy	-	Dictionary
		Mooring System Type	-	String
		Number of Mooring Lines per Device	-	Scalar
		Foundation System Type	-	String
	ASSESSMENTS			
		Gross Energy Production per Year (with no downtime losses)	kWh	Scalar
		Monthly Gross Energy Production per Year (with no downtime losses)	kWh	Scalar
		Efficiency per Subsystem,	-	List of Scalar
		Power Quality Ratio per Sea state	-	List
		CAPEX	€	Scalar
		MTTF	hrs^{-1}	Scalar
		Overall Environmental Impact	-	Scalar

6.3.1 THE DEVICE SUBGROUP

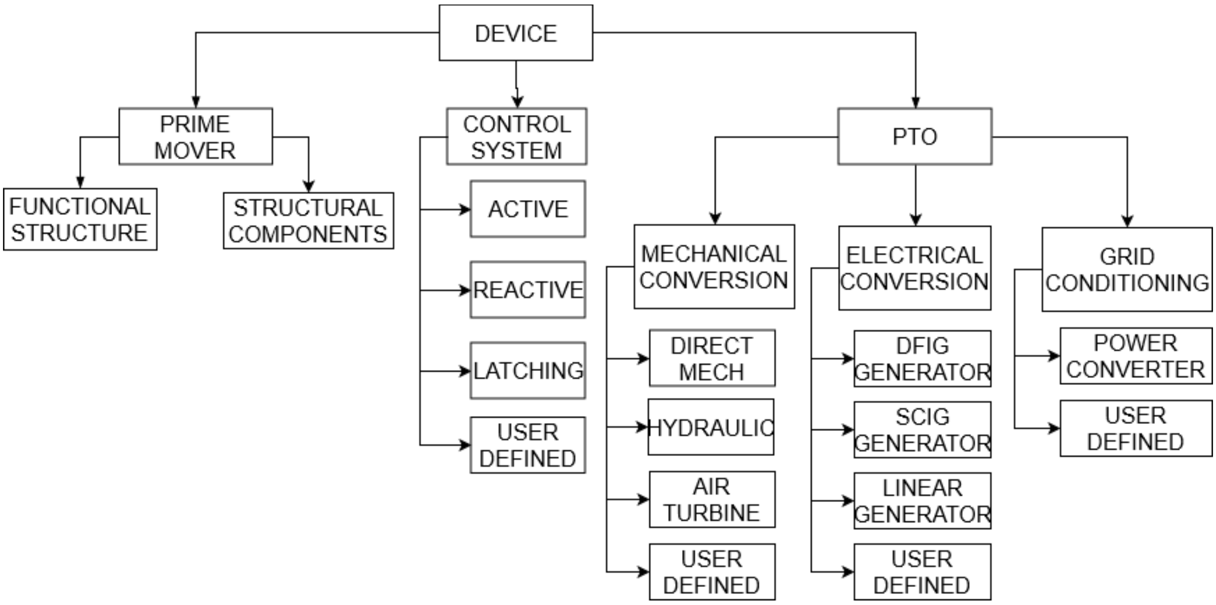

FIGURE 6-5: FAMILY TECHNOLOGY DESIGN, GROUP DEVICE

The Device Subgroup as seen in Figure 6-5, consider three main subgroups: Prime Mover, Control and PTO.

The main characteristics of the Device Object are summarised in Table 6.4.

TABLE 6.4: THE DEVICE OBJECT

DEVICE	**ID**		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Technology	-	string
		Type of Technology	-	string
		Type of mechanical conversion	-	string
		Type of electrical conversion		
		Type of grid conditioning		
		Pnom	kW	scalar
		Name Material & weight	name & kg	Array
	ASSESSMENTS			
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Failure rate	-	Scalar
		Risk priority number	-	Scalar
		Overall Environmental Impact	-	List
		Availability	-	Scalar
		Survivability	-	Scalar
		Maintainability	-	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Array ID}	[]	List
		Structure: {IDs}	[]	List
		Control: {IDs}	[]	List
		PTO: {IDs}	[]	List
	CONNECTION			
		Installation of Prime Mover {Operation IDs}	-	String
		O&M of Prime Mover {Operation IDs}	-	String
		Decommissioning of Prime Mover {Operation IDs}	-	String
		Connection to Wave/Tidal Statistics {ResourceId}	-	String

6.3.1.1 The Prime Mover

The list of the main attributes of the Prime Mover object are listed in Table 6.5. At this level of detail, the array effects of the hydrodynamic interactions are considered.

TABLE 6.5: THE PRIME MOVER OBJECT

PRIME MOVER	ID		-	String
	LOCATION	[x, y, z]	m	List of Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Technology (Wave/Tidal)	-	String
		Type of Technology	-	String
		Number of Prime Movers (devices= in the Array	-	Scalar
		Characteristic Length	m	Scalar
		Rated Capacity	kW	Scalar
		Array Hydrodynamic Characteristics and Performance	-	Specific Format
		Name Material & weight	[]	List of string and scalar
	ASSESSMENTS			
		Captured Annual Energy Production	kWh	scalar
		Array Power Matrix per sea state	kW	scalar
		Array Capture Length	m	scalar
		Hydrodynamic Efficiency	[]	List of scalars
		Failure rate	-	Scalar
		Risk priority number	-	Scalar
	HIERACHICAL CONNECTION			
		Part of {Device ID}	-	String
	CONNECTION			
		Installation of Prime Mover {Operation IDs}	-	String
		O&M of Prime Mover {Operation IDs}	-	String
		Decommissioning of Prime Mover {Operation IDs}	-	String
		Connection to Wave/Tidal Statistics {Resource ID}	-	String

Functional Structure

The list of the main attributes of the Functional Structure object are listed in Table 6.6. The functional structure is defined as the active part of the ocean energy converter, included support structure and ballast. At this level of detail, in terms of functionality the effects of the hydrodynamic interactions of the single devices are considered.

TABLE 6.6: THE FUNCTIONAL STRUCTURE OBJECT

MAIN STRUCTURE	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Characteristic Length	m	Scalar
		Rated Capacity	kW	Scalar
		Array Hydrodynamic Performance	-	Specific Format
		Name Material & weight of structure and ballast	kg	List of string and scalar
		Inertial Properties	kg – kgm	List
		Main Dimensions	m	list
	ASSESSMENTS			
		Annual Captured Energy Production (device)	kWh	scalar
		Captured Energy Production per Sea State (device)	kW	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Mech. Conversion ID}	-	String
	CONNECTION			
		Installation of Mech. Conv {Operation ID}	-	String
		O&M of Mech. Conv {Operation ID}	-	String
		Decommissioning of Mech. Conv {Operation ID}	-	String

Structural Components

This level of aggregation is out of scope within DTOceanPlus, i.e. the tools developed in DTOceanPlus cannot carry out a detailed design and analysis of structural components. However, given the increasingly importance that the design of the structural components has in the field of reliability and for the analysis of local stresses, the present framework of Digital Representation has included the possibility of expanding the representation itself accounting for them.

6.3.1.2 Control

The global characteristics of the object Control are included in Table 6.7. The Control sub-group could be further divided into four groups: Active in Table 6.8, Reactive Table 6.9, Latching Latching

Table 6.10 and User-defined Table 6.11. Not all the subgroups will be covered within the scope of DTOceanPlus.

TABLE 6.7: THE CONTROL OBJECT

CONTROL	ID		-	String
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Type of controller	-	string
		Pnom	kW	scalar
		Material name and weight	kg	Array
	ASSESSMENTS			
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Failure rate	-	Scalar
		Risk priority number	-	Scalar
	HIERACHICAL CONNECTION			
		Part of {Device ID}	-	Scalar
		Control Type {IDs}	-	Scalar
	CONNECTION			
		Installation of Control {Operation IDs}	-	List
		O&M of Control {Operation IDs}	-	List

Active

TABLE 6.8: THE CONTROL/ACTIVE OBJECT

ACTIVE	ID		-	String
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Pnom	kW	scalar
		Velocity distribution	[]	array
		load distribution	[]	array
		Material name and weight	kg	Array
		Main dimensions	m	Array
		Power	[]	array
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Control ID}		
	CONNECTION			
		Connection to phases (production, operation)	-	TBD
		Connection to site	-	TBD
		Connection to user selection	-	TBD

Reactive

TABLE 6.9: THE CONTROL/REACTIVE OBJECT

REACTIVE	ID		-	String
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Pnom	kW	scalar
		Velocity distribution	[]	array
		Load distribution	[]	array
		Power	[]	array
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Control ID}		
	CONNECTION			
		Connection to phases (production, operation)	-	TBD
		Connection to site	-	TBD
		Connection to user selection	-	TBD

Latching

TABLE 6.10: THE LATCHING OBJECT

LACHING	ID		-	String
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Pnom	kW	scalar
		Load distribution	[]	array
		Velocity distribution	[]	array
		Power	[]	array
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Control ID}		
	CONNECTION			
		Connection to phases (production, operation)	-	TBD
		Connection to site	-	TBD
		Connection to user selection	-	TBD

User Defined

TABLE 6.11: THE CONTROL/USER DEFINED OBJECT

PASSIVE	ID		-	String
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Pnom	kW	scalar
		Velocity distribution	[]	array
		load distribution	[]	array
		Power	[]	array
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Control ID}		
	CONNECTION			
		Connection to phases (production, operation)	-	TBD
		Connection to site	-	TBD
		Connection to user selection	-	TBD

6.3.1.3 PTO

The characteristics of the group PTO is described in Table 6.12.

TABLE 6.12: THE PTO OBJECT

PTO	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Type of mechanical conversion	-	string
		Number of PTO per device and total number of PTOs	-	Scalar
		Type of electrical conversion		String
		Type of grid conditioning		string
		Pnom of each PTO	kW	scalar
		Name Material & weight	name & kg	Array
		BoM	-	Dictionary
	ASSESSMENTS			
		Energy Production per Sea State per PTO	kW	Array
		Annual transformed Energy	kW	Scalar
		Reactive power per device per sea state	kW	Array
		Active power per device per sea state	kW	Array
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Failure rate	-	Scalar
		Risk priority number	-	Scalar
	HIERACHICAL CONNECTION			
		Part of {Device ID}	-	List of String
		Mechanical conversion {IDs}	-	List of String
		Electrical Conversion {IDs}	-	List of String
		Grid conditioning {IDs}	-	List of String
	CONNECTION		-	List of Scalar
		Installation of PTO {Operation IDs}	-	List of String
		O&M of PTO {Operation IDs}	-	List of String
		Decommissioning of PTO {Operation IDs}	-	List of String

Mechanical Conversion

The subgroup of Mechanical Conversion includes characteristics of the technology for the transformation of the mechanical energy and they are described in Table 6.13. Four different technology have been considered for mechanical conversion: the direct mechanical transformation n in Table 6.14, the hydraulic PTO in Table 6.15, an air turbine in Table 6.16 and a user defined PTO in Table 6.17.

TABLE 6.13: THE MECHANICAL CONVERSION OBJECT

	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Type	-	string
		Pnom	kW	scalar
		Name Material & weight	name & kg	Array
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {PTO ID}	-	String
		Type of Mech conversion: {Mech. Conv. ID}	-	String
	CONNECTION			
		Installation of Mech. Conv {Operation ID}	-	String
		O&M of Mech. Conv {Operation ID}	-	String
		Decommissioning of Mech. Conv {Operation ID}	-	String

DIRECT MECH

TABLE 6.14: THE DIRECT MECH OBJECT

DIRECT MECH	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Pnom	kW	scalar
		Speed in max	m/s	scalar
		Speed out max	rpm	scalar
		Stem length	m	scalar
		Name Material & weight	name & kg	Array
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Mech. Conversion ID}	-	String
	CONNECTION			
		Installation of Mech. Conv {Operation ID}	-	String
		O&M of Mech. Conv {Operation ID}	-	String
		Decommissioning of Mech. Conv {Operation ID}	-	String

HYDRAULIC

TABLE 6.15: THE HYDRAULIC CONVERSION OBJECT

HYDRAULIC	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Pnom	kW	scalar
		Piston diameter	m	scalar
		Stem length	m	scalar
		Name Material & weight	name & kg	Array
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Mech. Conversion ID}	-	String
	CONNECTION			
		Installation of Mech. Conv {Operation ID}	-	String
		O&M of Mech. Conv {Operation ID}	-	String
		Decommissioning of Mech. Conv {Operation ID}	-	String

AIR TURBINE

TABLE 6.16: THE AIR TURBINE CONVERSION OBJECT

AIR TURBINE	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Rotor Diameter	m	scalar
		Nominal Power	kW	scalar
		Type of turbine		string
		Name Material & weight	name & kg	Array
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Mech. Conversion ID}	-	String
	CONNECTION			
		Installation of Mech. Conv {Operation ID}	-	String
		O&M of Mech. Conv {Operation ID}	-	String
		Decommissioning of Mech. Conv {Operation ID}	-	String

USER DEFINED

TABLE 6.17: THE USER DEFINED CONVERSION OBJECT

USER DEFINED	ID		**-**	**String**
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Pnom	kW	scalar
		Name Material & weight	name & kg	Array
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Mech. Conversion ID}	-	String
	CONNECTION			
		Installation of Mech. Conv {Operation ID}	-	String
		O&M of Mech. Conv {Operation ID}	-	String
		Decommissioning of Mech. Conv {Operation ID}	-	String

Electrical Conversion

In the Electrical Conversion group, whose object is described in Table 6.18, the characteristics of the technology for the transformation into electrical energy are included. Four types of generators have been considered: the DFIG Generator in Table 6.19, the SCIG Generator in Table 6.20, the Linear Generator in Table 6.21 and a user defined generator in Table 6.22.

TABLE 6.18: THE ELECTRICAL CONVERSION OBJECT

ELECTRICAL CONVERSION	ID		**-**	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Type	-	string
		Pnom	kW	scalar
		Name Material & weight	name & kg	Array
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {PTO ID}	-	Scalar
		Type of Elect. conversion: {Elect Conv. ID}	-	Scalar
	CONNECTION			
		Installation of Elect. Conv {Operation ID}	-	String
		O&M of Elect. Conv {Operation ID}	-	String
		Decommissioning of Elect. Conv {Operation ID}	-	String

DFIG GENERATOR

TABLE 6.19: THE DFIG GENERATOR OBJECT

DFIG GENERATOR	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Pnom	kW	scalar
		Name Material & weight	name & kg	Array
		Component properties	-	Dictionary
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Elect. Conversion ID}	-	String
	CONNECTION			
		Installation of Mech. Conv {Operation ID}	-	String
		O&M of Mech. Conv {Operation ID}	-	String
		Decommissioning of Mech. Conv {Operation ID}	-	String

SCIG GENERATOR

TABLE 6.20: THE SCIG GENERATOR OBJECT

SCIG GENERATOR	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Pnom	kW	scalar
		Name Material & weight	name & kg	Array
		Component properties	-	Dictionary
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Elect. Conversion ID}	-	String
	CONNECTION			
		Installation of Mech. Conv {Operation ID}	-	String
		O&M of Mech. Conv {Operation ID}	-	String
		Decommissioning of Mech. Conv {Operation ID}	-	String

LINEAR GENERATOR

TABLE 6.21: THE LINEAR GENERATOR OBJECT

LINEAR GENERATOR	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Pnom	kW	scalar
		Name Material & weight	name & kg	Array
		Component properties	-	Dictionary
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Elect. Conversion ID}	-	String
	CONNECTION			
		Installation of Mech. Conv {Operation ID}	-	String
		O&M of Mech. Conv {Operation ID}	-	String
		Decommissioning of Mech. Conv {Operation ID}	-	String

USER DEFINED

TABLE 6.22: THE USER DEFINED GENERATOR OBJECT

USER DEFINED	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Pnom	kW	scalar
		Name Material & weight	name & kg	Array
		Component properties	-	Dictionary
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Elect. Conversion ID}	-	String
	CONNECTION			
		Installation of Mech. Conv {Operation ID}	-	String
		O&M of Mech. Conv {Operation ID}	-	String
		Decommissioning of Mech. Conv {Operation ID}	-	String

Grid Conditioning

In the Grid Conditioning group, whose object is described in Table 6.23, the characteristics of the technology for the input into grid. two types of grid conditioning systems have been considered: The Power Converter in Table 6.24 and a user defined one in Table 6.25.

TABLE 6.23: THE GRID CONDITIONING OBJECT

GRID CONDITIONING	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		cos fi	0-1	scalar
		Voltage out	V	scalar
		Voltage in	V	scalar
		Pnom	kW	scalar
		Efficiency	%	scalar
		Name Material & weight	name & kg	Array
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {PTO ID}		String
		Type of Grid Conditioning: {Elect. Conv. ID}		String
	CONNECTION			
		Installation of Grid Cond. {Operation ID}	-	String
		O&M of Grid Cond. {Operation ID}	-	String
		Decommissioning of Grid Cond. {Operation ID}	-	String

POWER CONVERTER

TABLE 6.24: THE POWER CONVERTER OBJECT

POWER CONVERTER	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Voltage in	V	scalar
		Voltage out	V	scalar
		Pnom	kW	scalar
		cos fi	0-1	scalar
		Name Material & weight	name & kg	Array
		Component properties	-	Dictionary
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Elect. Grid conditioning ID}	-	String
	CONNECTION			

		Installation of Grid Cond. {Operation ID}	-	String
		O&M of Grid Cond. {Operation ID}	-	String
		Decommissioning of Grid Cond. {Operation ID}	-	String

USER DEFINED

TABLE 6.25: THE GRID CONDITIONING/USER DEFINED OBJECT

USER DEFINED	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Voltage in	V	scalar
		Voltage out	V	scalar
		Pnom	kW	scalar
		cos fi	0-1	scalar
		Name Material & weight	name & kg	Array
		Component properties	-	Dictionary
	ASSESSMENTS			
		Efficiency	%	scalar
		Cost	€	scalar
		Failure rate	[0-1]	scalar
	HIERACHICAL CONNECTION			
		Part of: {Elect. Grid conditioning ID}	-	String
	CONNECTION			
		Installation of Grid Cond. {Operation ID}	-	String
		O&M of Grid Cond. {Operation ID}	-	String
		Decommissioning of Grid Cond. {Operation ID}	-	String

6.3.2 THE POWER TRANSMISSION

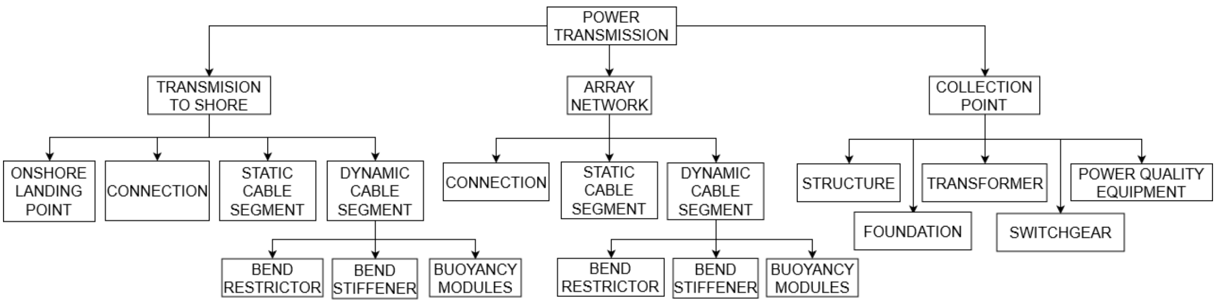

FIGURE 6-6: FAMILY TECHNOLOGY DESIGN, GROUP POWER TRANSMISSION

The Power Transmission Subgroup as seen in Figure 6-6, consider three main subgroups: The Transmission to Shore, the Array Network and the Collection point(s).

The main characteristics of the Power Transmission Object are summarised in Table 6.26.

TABLE 6.26: THE POWER TRANSMISSION TO SHORE OBJECT

POWER TRANSMISSION				
	ID		-	String
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Total transmission cable length	m	Scalar
		Total intra-array network cable length	m	Scalar
		Transmission voltage	V	Scalar
		Array voltage	V	Scalar
		Array topology type (direct, star, radial, loop, hybrid)	-	Dictionary
		Network topology connections	-	Dictionary
		BoM	-	Dictionary
	ASSESSMENTS			
		Delivered AEP	kWh	Scalar
		Delivered AEP per sea state	kWh	1D Array
		Delivered AEP including faults	kWh	Scalar
		Network Efficiency	%	Scalar
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Failure rate	-	Scalar
		Electric field	-	Scalar
		Magnetic field	-	Scalar
		Temperature modification	-	Scalar
		Collision risk	-	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Array ID}	-	List of Stringr
		Transmission to shore: {ID}	-	List of Stringr
		Array network: {optional ID}	-	List of Stringr
		Collection points: {optional IDs}	-	List of Stringr
		Connected to {Device ID}	-	List of Stringr
	CONNECTION			
		Installation of Power Transmission {Operation ID}	-	List of Stringr
		Maintenance of Power Transmission {Operation ID}	-	List of Stringr
		Decommissioning of Power Transmission {Operation ID}	-	List of Stringr

6.3.2.1 Transmission to Shore

TABLE 6.27: THE TRANSMISSION TO SHORE OBJECT

TRANSMISSION TO SHORE	ID		-	String
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Total Cable length	m	Scalar
		Transmission voltage	V	Scalar
		BoM	-	Dictionary
		Intermediate Nodes ID (list)	-	2D Array
		Intermediate Node position X, Y, Z (list)	m	List of Scalar
	ASSESSMENTS			
		Losses (per sea state)	-	Scalar
		Export cable capacity factor	-	Scalar
		Failure rate	-	Scalar
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Electric field	-	Scalar
		Magnetic field	-	Scalar
		Temperature modification	-	Scalar
	HIERACHICAL CONNECTION			
		Part of {Power Transmission ID}	-	Scalar
		Static cables {IDs}	-	List of Stringr
		Connectors {IDs}	-	List of Stringr
	CONNECTION			
		Installation of Transmission to shore {Operation ID}	-	List of Stringr
		Maintenance of Transmission to shore {Operation ID}	-	List of Stringr
		Decommissioning of Transmission to shore {Operation ID}	-	List of Stringr

Onshore Landing Point

TABLE 6.28: THE ARRAY NETWORK / ONSHORE LANDING POINT OBJECT

ONSHORE LANDING POINT	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Installation method	-	Dictionary
		Burial depth	m	Scalar
		Protection method	-	Dictionary
	ASSESSMENTS			
		Delivered AEP per OLP	kWh	Scalar
		Delivered AEP per OLP per sea state	kWh	1D Array
		Delivered AEP per OLP including faults	kWh	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Array Network ID}	-	String
		Connected to: {Node ID}	-	String
	CONNECTION			
		Installation of OLP {Operation ID}	-	String
		Maintenance of OLP {Operation ID}	-	String
		Decommissioning of OLP {Operation ID}	-	String

Connection

TABLE 6.29: THE ARRAY NETWORK / CONNECTION OBJECT

CONECCTION	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Type	-	Dictionary
		Transmission voltage	V	Scalar
		Component properties	-	Dictionary
	ASSESSMENTS			
		Dry CAPEX	€	Scalar
		Failure rate	-	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Array Network ID}	-	String
		Start connected to: {node IDs}	-	String
		End connected to: {Node ID}	-	String
	CONNECTION			
		Installation of connection {Operation ID}	-	String
		Maintenance of connection {Operation ID}	-	String
		Decommissioning of connection {Operation ID}	-	String

Static Cable Segment

TABLE 6.30: THE TRANSMISSION TO SHORE/ STATIC CABLE SEGMENT OBJECT

STATIC CABLE SEGMENT	ID		-	String
	LOCATION	Start point [x, y, z]	m	1D Array
		End point [x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Segment Length	m	Scalar
		Route coordinates	-	2D array
		Installation method	-	Dictionary
		Burial depth	m	1D array
		Protection method	-	Dictionary
		Component properties	-	Dictionary
	ASSESSMENTS			
		Losses (per sea state)	-	1D array
		Export cable capacity factor	-	Scalar
		Failure rate	-	Scalar
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Electric field	-	Scalar
		Magnetic field	-	Scalar
		Temperature modification	-	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Array Network ID}	-	String
		Start connected to: {node ID}	-	String
		End connected to: {Node ID}	-	String
	CONNECTION			
		Installation of static cable {Operation ID}	-	String
		Maintenance of static cable {Operation ID}	-	String
		Decommissioning of static cable {Operation ID}	-	String

Dynamic Cable Segment

TABLE 6.31: THE TRANSMISSION TO SHORE / DYNAMIC CABLE OBJECT

DYNAMIC CABLE SEGMENT	ID		-	String
	LOCATION	Start point [x, y, z]	m	1D Array
		End point [x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Segment Length	m	Scalar
		Route coordinates	-	2D array
		Installation method	-	Dictionary
		Burial depth	m	1D array
		Protection method	-	Dictionary
		Buoyancy approach	-	Dictionary
		Mechanical properties	-	Dictionary
		Bending ratio	-	Dictionary
		Component properties	-	Dictionary
	ASSESSMENTS			
		Losses (per sea state)	-	1D array
		Export cable capacity factor	-	Scalar
		Failure rate	-	Scalar
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Electric field	-	Scalar
		Magnetic field	-	Scalar
		Temperature modification	-	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Umbilical ID}	-	**String**
		Start connected to: {node ID}	-	**String**
		End connected to: {Node ID}	-	**String**
	CONNECTION			
		Installation of dynamic cable {Operation ID}	-	**String**
		Maintenance of dynamic cable {Operation ID}	-	**String**
		Decommissioning of dynamic cable {Operation ID}	-	**String**

BEND RESTRICTOR

TABLE 6.32: THE BEND RESTRICTOR OBJECT

BEND RESTRICTOR	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Component properties	-	Dictionary
	ASSESSMENTS			
		Dry CAPEX	€	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Umbilicals ID}		**String**

BEND STIFFNER

TABLE 6.33: THE BEND STIFFNER OBJECT

BEND STIFFENER	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Component properties	-	Dictionary
	ASSESSMENTS			
		Dry CAPEX	€	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Umbilicals ID}		**String**

BUOYANCY MODULES

TABLE 6.34: THE BUOYANCY MODULES OBJECT

BUOYANCY MODULES	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Component properties	-	Dictionary
	ASSESSMENTS			
		Dry CAPEX	€	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Umbilicals ID}		**String**

6.3.2.2 Array Network

TABLE 6.35: THE ARRAY NETWORK OBJECT

ARRAY NETWORK	**ID**		-	String
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Total Cable length	m	Scalar
		Transmission voltage	V	Scalar
		BoM	-	Dictionary
		Intermediate Nodes ID (list)	-	2D Array
		Intermediate Node position X, Y, Z (list)	m	List of Scalar
	ASSESSMENTS			
		Losses (per sea state)	-	Scalar
		Export cable capacity factor	-	Scalar
		Failure rate	-	Scalar
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Electric field	-	Scalar
		Magnetic field	-	Scalar
		Temperature modification	-	Scalar
	HIERACHICAL CONNECTION			
		Part of {Power Transmission ID}	-	String
		Static cables {IDs}	-	List of String
		Connectors {IDs}	-	List of String
	CONNECTION			
		Installation of Transmission to shore {Operation ID}	-	List of String
		Maintenance of Transmission to shore {Operation ID}	-	List of String
		Decommissioning of Transmission to shore {Operation ID}	-	List of String

Connection

TABLE 6.36: THE ARRAY NETWORK / CONNECTION OBJECT

CONECCTION	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Type	-	Dictionary
		Transmission voltage	V	Scalar
		Component properties	-	Dictionary
	ASSESSMENTS			
		Dry CAPEX	€	Scalar
		Failure rate	-	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Array Network ID}	-	String
		Start connected to: {node IDs}	-	String
		End connected to: {Node ID}	-	String
	CONNECTION			
		Installation of connection {Operation ID}	-	String
		Maintenance of connection {Operation ID}	-	String
		Decommissioning of connection {Operation ID}	-	String

Static Cable Segment

TABLE 6.37: THE ARRAY NETWORK/ STATIC CABLE SEGMENTOBJECT

STATIC CABLE SEGMENT	ID		-	**String**
	LOCATION	Start point [x, y, z]	m	1D Array
		End point [x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Segment Length	m	Scalar
		Route coordinates	-	2D array
		Installation method	-	Dictionary
		Burial depth	m	1D array
		Protection method	-	Dictionary
		Component properties	-	Dictionary
	ASSESSMENTS			
		Losses (per sea state)	-	1D array
		Export cable capacity factor	-	Scalar
		Failure rate	-	Scalar
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Electric field	-	Scalar
		Magnetic field	-	Scalar
		Temperature modification	-	Scalar
	HIERACHICAL CONNECTION			

		Part of: {Array Network ID}	-	String
		Start connected to: {node ID}	-	String
		End connected to: {Node ID}	-	String
	CONNECTION			
		Installation of static cable {Operation ID}	-	String
		Maintenance of static cable {Operation ID}	-	String
		Decommissioning e of static cable {Operation ID}	-	String

Dynamic Cable Segment

TABLE 6.38: THE ARRAY NETWORK / DYNAMIC CABLE OBJECT

DYNAMIC CABLE SEGMENT	ID		-	String
	LOCATION	Start point [x, y, z]	m	1D Array
		End point [x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Segment Length	m	Scalar
		Route coordinates	-	2D array
		Installation method	-	Dictionary
		Burial depth	m	1D array
		Protection method	-	Dictionary
		Buoyancy approach	-	Dictionary
		Mechanical properties	-	Dictionary
		Bending ratio	-	Dictionary
		Component properties	-	Dictionary
	ASSESSMENTS			
		Losses (per sea state)	-	1D array
		Export cable capacity factor	-	Scalar
		Failure rate	-	Scalar
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Electric field	-	Scalar
		Magnetic field	-	Scalar
		Temperature modification	-	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Umbilical ID}	-	String
		Start connected to: {node ID}	-	String
		End connected to: {Node ID}	-	String
	CONNECTION			
		Installation of dynamic cable {Operation ID}	-	String
		Maintenance of dynamic cable {Operation ID}	-	String
		Decommissioning e of dynamic cable {Operation ID}	-	String

BEND RESTRICTOR

TABLE 6.39: THE BEND RESTRICTOR OBJECT

BEND RESTRICTOR	**ID**		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Component properties	-	Dictionary
	ASSESSMENTS			
		Dry CAPEX	€	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Umbilicals ID}		String

BEND STIFFNER

TABLE 6.40: THE BEND STIFFNER OBJECT

BEND STIFFENER	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Component properties	-	Dictionary
	ASSESSMENTS			
		Dry CAPEX	€	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Umbilicals ID}		String

BUOYANCY MODULES

TABLE 6.41: THE BUOYANCY MODULES OBJECT

BUOYANCY MODULES	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Component properties	-	Dictionary
	ASSESSMENTS			
		Dry CAPEX	€	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Umbilicals ID}		String

6.3.2.3 Collection Point

TABLE 6.42: THE COLLECTION POINT OBJECT

COLLECTION POINT	**ID**		-	String
	LOCATION	Unit centre of gravity (x, y, z)		List of 1D array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Type	-	String
		Foundation type	-	String
		Number of input connections	-	Scalar
		Number of output connections	-	Scalar
		Type of input connector(s)	-	Dictionary
		Type of output connector(s)	-	Dictionary
		Rated power	kVA	Scalar
		Busbar configuration	-	Dictionary
		Cooling	-	Dictionary
		BoM	-	Dictionary
	ASSESSMENTS			
		Failure rate	-	Scalar
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Temperature modification	-	Scalar
		collision risk	-	Scalar
		Electric field	-	Scalar
		Magnetic field	-	Scalar
	HIERACHICAL CONNECTION			
		Part of {Power Transmission ID}	-	String
		Export cable {IDs}	-	String
		Array cables {IDs}	-	String
		Devices connected {IDs}	-	String
		Structure {ID}	-	String
		Foundation {ID}	-	String
		Transformer {ID}	-	String
		Switchgear {ID}	-	String
		Power Quality Equipment {ID}	-	String
	CONNECTION			
		Installation of foundation {Operation ID}	-	String
		Maintenance of foundation {Operation ID}	-	String
		Decommissioning e of foundation {Operation ID}	-	String

Structure

TABLE 6.43: THE COLLECTION POINT STRUCTURE OBJECT

STRUCTURE	ID		-	String
	LOCATION	Unit centre of gravity (x, y, z)		1D array
	PHYSICAL AND FUNCTIONAL PROPERTIES			List
		Type	-	Dictionary
		Material	-	Dictionary
		Main dimensions [L, W, H]	m	1D matrix
		Mass	kg	Scalar
	ASSESSMENTS			
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Temperature modification	-	Scalar
		Collision risk	-	Scalar
		Failure rate	-	Scalar
	HIERACHICAL CONNECTION			
		Part of {Collection Point ID}	-	String
		Foundation {ID}	-	String
	CONNECTION			
		Installation of structure {Operation ID}	-	String
		Maintenance of structure {Operation ID}	-	String
		Decommissioning e of structure {Operation ID}	-	String

Foundation

TABLE 6.44: THE COLLECTION POINT/FOUNDATION OBJECT

FOUNDATION	ID		-	String
	LOCATION	Unit centre of gravity (x, y, z)		1D array
	PHYSICAL AND FUNCTIONAL PROPERTIES			List
		Type	-	Dictionary
		Material	-	Dictionary
		Main dimensions [L, W, H]	m	1D matrix
		Mass	kg	Scalar
	ASSESSMENTS			
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Collision risk	-	Scalar
		Failure rate	-	Scalar
	HIERACHICAL CONNECTION			
		Part of {Collection Point ID}	-	String
		Structure {ID}	-	String
	CONNECTION			
		Installation of foundation {Operation ID}	-	String
		Maintenance of foundation {Operation ID}	-	String
		Decommissioning e of foundation {Operation ID}	-	String

Transformer

TABLE 6.45: THE TRANSFORMER OBJECT

TRANSFORMER	**ID**		**-**	String
	LOCATION	Unit centre of gravity (x, y, z)		1D array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Input voltage	V	Scalar
		Output voltage	V	Scalar
		Rated power	kVA	Scalar
		Main dimensions [L, W, H]	m	1D matrix
		Mass	kg	Scalar
		Component properties	-	Dictionary
	ASSESSMENTS			
		Efficiency		
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Electric field	-	Scalar
		Magnetic field	-	Scalar
		Failure rate	-	Scalar
	HIERACHICAL CONNECTION			
		Part of {Collection Point ID}	-	**String**
	CONNECTION			
		Installation of transformer {Operation ID}	-	String
		Maintenance of transformer {Operation ID}	-	String
		Decommissioning e of transformer {Operation ID}	-	String

Switchgear

TABLE 6.46: THE SWITCHGEAR OBJECT

SWITCHGEAR	ID		**-**	**String**
	LOCATION	Unit centre of gravity (x, y, z)		1D array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Rated voltage	V	Scalar
		Main dimensions [L, W, H]	m	1D matrix
		Mass	kg	Scalar
		Component properties	-	Dictionary
	ASSESSMENTS			
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Electric field	-	Scalar
		Magnetic field	-	Scalar
		Failure rate	-	Scalar
	HIERACHICAL CONNECTION			
		Part of {Collection Point ID}	-	String
	CONNECTION			
		Installation of switchgear {Operation ID}	-	String
		Maintenance of switchgear {Operation ID}	-	String
		Decommissioning e of switchgear {Operation ID}	-	String

Power Quality Equipment

TABLE 6.47: THE POWER QUALITY EQUIPMENT OBJECT

POWER QUALITY EQUIPMENT	ID		-	String
	LOCATION	Unit centre of gravity (x, y, z)		1D array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Rated voltage	V	Scalar
		Component properties	-	Dictionary
	ASSESSMENTS			
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Electric field	-	Scalar
		Magnetic field	-	Scalar
		Failure rate	-	Scalar
	HIERACHICAL CONNECTION			
		Part of {Collection Point ID}		String
	CONNECTION			
		Installation of power quality equipment {Operation ID}	-	String
		Maintenance of power quality equipment {Operation ID}	-	String
		Decommissioning of power quality equipment {Operation ID}	-	String

6.3.3 THE STATION KEEPING

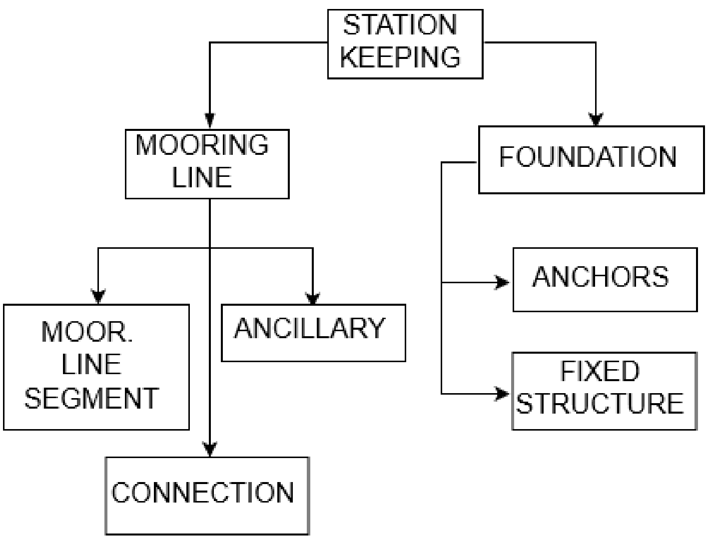

FIGURE 6-7: FAMILY TECHNOLOGY DESIGN, GROUP STATION KEEPING

6.3.3.1 Mooring Line

TABLE 6.48: THE MOORING LINE OBJECT

MOORING LINE	**ID**		-	String
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Intermediate Nodes ID	-	List of Integer
		Intermediate Node position X, Y, Z	m	2D Array
		Node external forces	N	List of Scalar
		Line total length	m	Scalar
		Suspended length	m	Scalar
		Breaking load	N	Scalar
		Pretension	N	Scalar
		Mooring stiffness matrix (equilibrium position)	N/m, N/rad, Nm/rad, Nm/m	2D Array
		BoM	-	Dictionary
	ASSESSMENTS			
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Failure rate	-	Scalar
		Risk priority number	-	Scalar
		Turbidity	-	Scalar
		Reef effect	-	Scalar
		Underwater noise	-	Scalar
	HIERACHICAL CONNECTION			
		Part of {Station keeping ID}	-	String
		Mooring line Segments {IDs}	-	List of String
		Connection Link {IDs}	-	List of String
		Ancillary {IDs}	-	List of String
		Foundations {IDs}	-	List of String
	CONNECTION			
		Installation of mooring lines {Operation IDs}	-	List of String
		Maintenance of mooring lines {Operation IDs}	-	List of String
		Decommissioning of mooring lines {Operation IDs}	-	List of String

Mooring Line Segment

TABLE 6.49: THE MOORING LINE SEGMENT OBJECT

MOORING LINE SEGMENT	ID		**-**	String
	LOCATION	Start point [x, y, z]	m	1D Array
		End point [x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Type	-	String
		Length	m	Scalar
		Diameter	m	Scalar
		Wet/ Dry mass	kg	Scalar
		Minimum breaking load	N	Scalar
		Various material properties	-	Dictionary
		Component properties	-	Dictionary
	ASSESSMENTS			
		Segment cost	€	Scalar
		Failure rate	-	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Mooring Line ID}	-	String
		Start connected to: {Node ID}	-	String
		End connected to: {Node ID}	-	String

Connection

TABLE 6.50: THE CONNECTION OBJECT

CONNECTION	ID		-	**String**
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Type	-	String
		Wet/ Dry mass	kg	Scalar
		Minimum breaking load	N	Scalar
		Component properties	-	Dictionary
	ASSESSMENTS			
		Cost	€	Scalar
		Failure rate	-	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Mooring Line ID}	-	String
		Start connected to: {Node ID}	-	String
		End connected to: {Node ID}	-	String
	CONNECTION			
		Installation of Connection {Operation ID}	-	String

Ancillary

TABLE 6.51: THE ANCILLARY OBJECT

ANCILLARY	ID		-	**String**
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Type	-	String
		Wet/ Dry mass	kg	Scalar
		Minimum breaking load	N	Scalar
		Buoyancy	N	Scalar
		Component properties	-	Dictionary
	ASSESSMENTS			
		Cost	€	Scalar
		Failure rate	-	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Mooring Line ID}		String
		Start connected to: {Node ID}	-	String
		End connected to: {Node ID}	-	String
	CONNECTION			
		Installation of Ancillary Component {Operation ID}	-	String

6.3.3.2 Foundation

TABLE 6.52: THE FOUNDATION OBJECT

FOUNDATION	**ID**		-	String
	LOCATION	[x, y, z]	m	List of Integers
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Type	-	List of Integers
		Number	-	Integer
		BoM	-	Dictionary
	ASSESSMENTS			
		Dry CAPEX	€	Scalar
		CAPEX	€	Scalar
		OPEX	€	Scalar
		Failure rate	-	Scalar
		Risk priority number	-	Scalar
		Turbidity	-	Scalar
		Reef effect	-	Scalar
	HIERACHICAL CONNECTION			
		Part of {Station Keeping ID}		String
		Anchors {IDs}		String
		Fixed Structure foundations {IDs}		String

Anchor

TABLE 6.53: THE ANCHOR OBJECT

ANCHOR	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Type	-	String
		Mass	kg	Scalar
		Drag	m	Scalar
		Penetration	m	Scalar
		Holding capacity	N	Scalar
		Component properties	-	Dictionary
	ASSESSMENTS			
		Cost	€	Scalar
		Failure rate	-	Scalar
	HIERACHICAL CONNECTION			

		Part of: {Foundation ID}	-	String
		Start connected to: {node ID})	-	String
	CONNECTION			
		Installation of anchor {Operation ID}	-	String
		Decommissioning of anchor {Operation ID}	-	String

Fixed Structure

TABLE 6.54: THE FIXED STRUCTURE OBJECT

FIXED STRUCTURE	ID		-	String
	LOCATION	[x, y, z]	m	1D Array
	PHYSICAL AND FUNCTIONAL PROPERTIES			
		Type	-	String
		Mass	kg	Scalar
		Main dimensions [L, W, H]	m	1D matrix
		Penetration	m	Scalar
		Holding capacity	N	Scalar
		Component properties	-	Dictionary
	ASSESSMENTS			
		Cost	€	Scalar
		Failure rate	-	Scalar
	HIERACHICAL CONNECTION			
		Part of: {Foundation ID}	-	String
		Start connected to: {node ID})	-	String
	CONNECTION			
		Installation of foundation fixed structure {Operation ID}	-	String
		Decommissioning of fixed structure {Operation ID}	-	String

6.4 PHASES FAMILY

The Phase Family description is in Figure 3-7. The Phase family is the most homogenous among the different families. Indeed, each object in the family will have exactly the same attributes, independently to the level of aggregation.

Each object in this class will have the structure in Table 6.55

TABLE 6.55. OBJECTS IN THE PHASES FAMILY

PHASES	**ID**		-	String
	NAME		-	String
	TYPE			String
	START/END			
		Start date	-	Date
		End Date	-	Date
	DURATION			
		Total Duration	h	Scalar
		Duration at Sea	h	Scalar
		Duration at Port	h	Scalar
		Waiting time	h	Scalar
		Mobilisation Time	h	Scalar
	VESSELS, PORTS, EQUIPMENT			
		Type of Vessel	-	String
		Number of Vessels	-	Scalar
		Port	-	String
		Other Equipment	-	String
		Operating Limiting Conditions [Hs, Tp, Vc, Vw]	[m, s, m/s, m/s]	List of scalars
	ASSESSMENTS			
		Downtime Hours [h]		
		Vessel/equipment consumption		
		Vessel Route [list of coordinates]		
		Operation cost		
		Production of CO_2 and other pollutants		
		Number of crew/workers		
		Risk of Collision (in case of Vessel operation)		
		Underwater noise		
	CONNECTION WITH PHASE			
		Is Part of {Operation ID}	-	List of strings
	CONNECTION WITH TECHNOLOGY DESIGN			
		Technology (ies) involved	-	List of strings
	CONNECTION WITH SITE			
		Id of the Time Series	-	List of strings

The Planning & Development sub-group has been included in the Digital Representation; however, this phase of the lifecycle of the project is out of the scope of DTOceanPlus Deployment Design tools, and for this reason it has not been characterised further.

6.4.1 INSTALLATION & COMMISSIONING

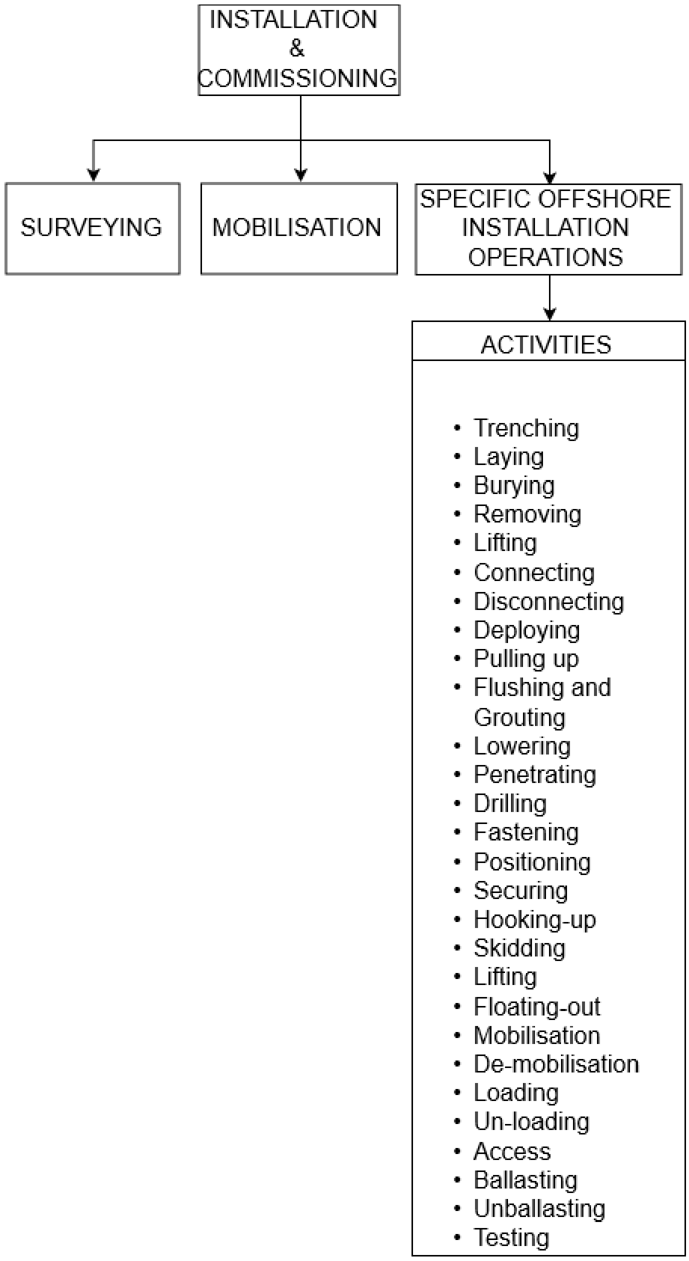

FIGURE 6-8: FAMILY PHASES, GROUP INSTALLATION & COMMISSIONING

Each object in this class will have the structure in Table 6.55.

6.4.2 OPERATION & MAINTENANCE

Each object in this class will have the structure in Table 6.55.

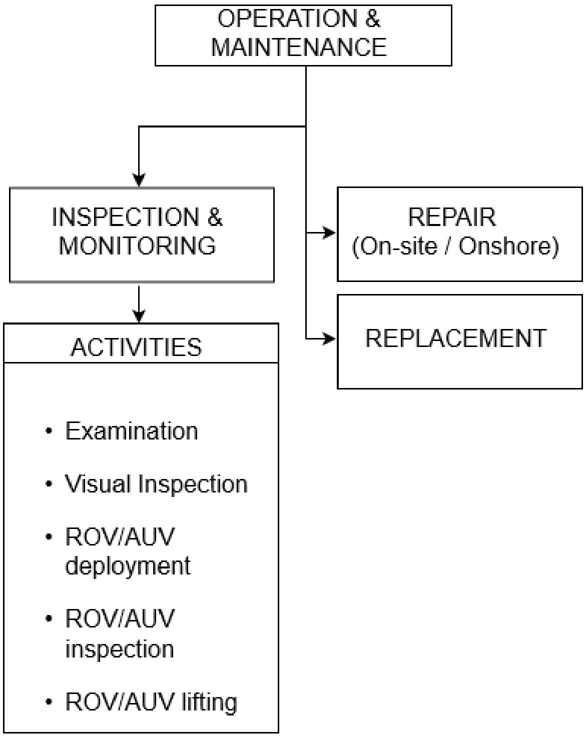

FIGURE 6-9: FAMILY PHASES, GROUP OPERATION & MAINTENANCE

6.4.3 DECOMISSIONING

This object will have the structure in Table 6.55.

CONTACT DETAILS

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Naval Energies terminated its participation on 31st August 2018 and
EDF terminated its participation on 31st January 2019.

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