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ScienceDirect

Procedia CIRP 69 (2018) 523 – 528

www.elsevier.com/locate/procedia

25th CIRP Life Cycle Engineering (LCE) Conference, 30 April – 2 May 2018, Copenhagen, Denmark

Life cycle model and metrics in shipbuilding: how to use them in the preliminary design phases

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Abstract

Maritime vessels are complex products with long service life and great costs of building, manning, operating, maintaining and repairing. The paper aims to introduce a specific life cycle model and related metrics in shipbuilding design, supporting decision-making processes of material selection, manufacturing/assembly practices, maintenance, use, etc. The model provides a common structure for life cycle assessment (LCA) and life cycle cost analysis (LCCA) including the way to retrieve and to collect necessary data for the analysis starting from the available project documentation and design models. Different design configurations (materials, welding methods, etc.) for hull and hatches of a luxury yacht have been analysed using the proposed model.

Keywords: LCCA; LCA; shipbuilding; design; maritime vessels.

1. Introduction

The project of large and complex products like ships, ferries and offshore vessels is a long process which includes all the activities until the product delivery (design phase, construction phase, etc.). It is widely known that decisions made during the early design phases have a great impact on the overall life cycle (e.g. costs, performances, etc.). Life cycle management is a challenging task for maritime transportation means, which have long lifespans (more than 15-20 years) and different operative scenarios. In addition, new environmental regulations and market requirements in this field require to consider life cycle aspects during the design phase [1].

Starting from the last decade, life cycle approaches have been applied in shipbuilding. Life cycle assessment (LCA) allows to calculate products/services environmental load [2]. Life cycle costing analysis (LCCA) allows the assessment of acquisition, running (e.g. fuel consumptions, operations, service, etc.) and disposing costs [3].

This paper aims to define a suitable life cycle model and metrics for environmental and cost analyses in shipbuilding. In particular, research objectives are: (i) to develop a consistent and robust methodology for life cycle evaluation, (ii) to establish a framework for life cycle inventory starting from available project documentation and, (iii) to provide life cycle indicators (both economic and environmental) as design metric for long-term decision making strategies. The novelty of the paper is the integration of ad-hoc and fragmented methods into a common standard for life cycle analysis in shipbuilding and ship design. The paper is structured as follow: after literature analysis in this field (§2), the proposed framework is described (§3). Different configurations of materials and manufacturing processes used to develop hull

doi:10.1016/j.procir.2017.11.071

and hatches of a luxury yacht are analyzed (§4) and obtained results are reported (§5). Lastly, conclusions and future work are proposed (§6).

2. State of the art about life cycle in ship design

Maritime vessels are complex products that follow, as standard practice, the traditional flow of product design [4]. Traditional design workflow encompass requires elicitation, conceptual design, embodiment design and detail design [5]. It is well known, however, that this niche market requires specific paradigms that need to be developed properly to take into account specific design constrains and requirements [6]. In particular, requirements are resulting from the purpose of the vessel and the operative use scenario. An overview of vessel typologies is presented in Fig. 1.

Fig. 1. Main vessel typologies.

Although vessels are different in size and typologies, common functional groups can be identified: (i) *Hull and superstructure*, (ii) *Outfitting*, (iii) *Machinery and propulsion*, (iv) *Electrical navigation and communication*, (v) *Piping system*, (vi) *HVAC*, (vii) *Accommodation*, (viii) *Painting and insulation* [7,8,9]. Each group (building module) can be further divided into other subgroups.

Due to product complexity, ship design and shipbuilding are becoming integrated activities and players involved in these processes are large in number. In this context, information and data sharing needs to be managed in an efficient way. Different design suites for project life cycle management have been developed in recent years to cope this problem [10,11]. Product lifecycle management (PLM) and product data management (PDM) are increasingly deployed in the maritime vessel design and construction phases with the aim to manage large amounts of data [12]. However, these systems are not decision-making tools able to decrease product costs and environmental loads throughout the entire lifetime [13]. The use of those design suites is limited until the vessel delivery without any extension to the service life. An extension of this boundary can be done for supporting the handover process from the shipyard to the vessel owner. Indeed, most of the information required for the correct management of the vessel are part of the project documentation stored in those repositories [14]. A life cycle analysis implies an holistic life cycle approach which goes further than cost and environmental assessment until vessel delivery. LCA is a standardized approach for environmental assessments of products and services, addressing their potential impacts with a cradle-to-grave perspective. LCA allows to establish environmental oriented guidelines and it can be applied in different fields and human activities [2]. LCCA is a well-known method in this field for the analysis of product/service life cycle costs, including running costs (e.g. fuel consumptions, service/maintenance, etc.). LCCA approach is used by designers/engineers in the project cost management as well as by potential buyer in the purchasing decision process [3]. LCA and LCCA methods have been developed for different purpose and, in most of the cases, they use different models, boundary conditions and data inputs. Literature highlights few case studies on LCA [15,16,17] and LCCA [18,19] of maritime vessels. Several issues have been identified concerning the use of LCA/LCCA in shipbuilding such as: (i) fragmented tools [20], (ii) data sharing among design departments [21], (iii) time-consuming data collection (inventory) [22] and, (iv) how to use the assessment results [23].

3. Method and metrics

This section describes, firstly, how life cycle model has been defined considering the peculiarities of shipbuilding context and, secondly, how the environmental metrics have been characterized

3.1. Proposed lifecycle model

The proposed model starts with the analysis of existing frameworks and standards in other context. For example, ISO-15686 standard (Buildings and constructed assets - Service-life planning) has been used as bases to perform lifecycle cost analysis. Likewise, ISO-14040 standard (Environmental management - Life cycle assessment) has been used for the environmental assessments. The two standards have not been developed for the life cycle analysis in shipbuilding context but they can be adjusted based on the specific needs of this field. In both cases, it is necessary to introduce the concept of *"functional unit"* [2]. The definition of the functional unit is a key aspect: it allows to make a comparison among different vessel typologies as well as to create a correct inventory model in which inputs and outputs are attributed to the reference flow (product system). Functional unit has been defined as "*the construction and the disposal of vessel modules for the transportation of persons, goods and/or operational activities by sea for a period of 20 years*". It is worth to notice that functional unit allows to consider the construction and the disposal of the overall vessel or part of it (modules). So doing, module alternatives can be analyzed