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Methodology for the ship exploitation feedback inclusion for improving the ship design and production process based on adjusted QFD method

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ABSTRACT

The relevant regulations of classification societies, national governments, IMO resolutions are included in the ship design and production process. However, it was noted that the shipyard does not include seaman's experiential perception to a higher level, coming from specific requests and observations during the operation and maintenance of the ship. Such requests are based on good marine practice, for which the shipyards do not have a sufficient level of experience and feedback which leads to additional works and alterations to customer requests and expectations. Therefore, the authors in this paper propose a methodology for the implementation of the feedback from the exploitation of the ship with the purpose of improving the ship design and production process to reduce costs and to improve ship efficiency in exploitation. In the first part of the proposed methodology, the collection and analysis of feedback is made using the expert approach and the relevant documentation in order to identify the most common groups of remarks. Such analysis was used as an input within the adjusted QFD method for identification and ranking of those ship design and production processes that affect mostly on such remarks. Furthermore, the matrix of quality control is proposed within relevant sub-processes, and the guidelines for the remarks solving within ship design and construction process are defined. In this paper, the authors have primarily analysed outfitting and equipment related issues which are often emphasised as more critical to a ship hull structure production, though, structure issues are set for further research. Finally, a typical example of such guidelines implementation for improving the ship design and construction process is given.

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List of symbols

CWF_j	*j-th* calculated weight factor
N_i	*i-th* column
W_i	*i-th* wight factor
NW_i	*i-th* normalized wight factor
QFD	Quality Function Deployment

1 Introduction

The relevant regulations of classification societies, national governments, IMO resolutions are included within ship design and production. However, it was noted that the shipyard, to a sufficient level, does not include experiential component of shipowners, arising from specific requests and observations during the operation and maintenance of the ship. Such requests are based on good seamanship practice, for which the shipyards naturally do not have high level of experience and feedback information which generally leads to additional works and alterations to customer requests and expectations. Furthermore, such requests are often in the late phase of ship production when reworks are particularly expensive. For that matter, during the ship design and production process, a special attention should be paid to the equipment installation, machinery and devices so as to ensure the efficient functioning, easy access, maintenance and repairs with high security and protection at work and the pleasure of staying and working on board a vessel, [1]. As, it should be recalled, for a seaman the ship is a home and a workplace for 24h hours a day. Hence, in this paper, remarks and feedback information from seamen and shipowners, during the ship production and exploitation, have been collected. After the data collection phase, remarks are systematized according to the groups of basic problems and the frequency of their occurrence during the ship production and operation.

Such data were used as an input within the adjusted QFD method for identification and ranking those ship design and production sub-processes that influence gathered remarks the most. Furthermore, the matrix of quality control is proposed within relevant sub-processes, and the guidelines for the remarks solving ship design and construction process are defined, with the goal to shorten the ship production, reduce costs and improve the quality of the ship. In this paper, the authors primarily analysed outfitting and equipment related issues which are often emphasised as more critical to a ship hull structure production, though, structure issues are set for further research. Finally, an example of such guidelines implementation for improving the ship design and construction process is given.

2 Problem definition

It is known, and at the global level several times acknowledged, that Croatian shipyards ultimately deliver the ship of high quality and functionality to the satisfaction of the shipowner. However, it is often accompanied by additional costs of various corrective actions, arising from the shipowner remarks, and with regard to raising the quality of, primarily in terms of easy maintenance, functionality, repair and residence on the ship which affects the ship production cost increase. Such costs can be difficult to collect from the shipyard because such remarks and reworks the shipping company often classifies as errors of the shipyard and as a rule, they do not have to be. In addition, the shipyard is often not in a good negotiating position, because there is no formally approved document or instance to invoke on, as in the case of classification and system documentation. Such situation opens up the space for the vagueness and misunderstandings regarding the processing of complaints, which in generally affect the cost of ship production negatively and interfere with the normal process of ship construction. Certain recommendations and guidelines of classification societies [2], and IMO and SOLAS [3], [4], already exist. However, the authors believe that they are not sufficiently comprehensive, accurate and adapted to the specific binding of the shipyard and are not subject to the approval of classification societies, but only depend on the acceptance by the shipowner, which is certainly not a good enough negotiating position for the shipyard. Therefore, the authors proposes the establishment of a methodology based on expert approach and adjusted QFD method for identifying critical points in the ship design and production process that most affect the collected remarks and feedback during ship production and exploitation. Furthermore, the control matrix for sub-processes is suggested and guidelines for the remarks solving within ship design and construction process are defined to decrease remarks occurring, as to decrease the cost and duration of ship production with improved quality and to ensure a better negotiating position for a shipyard, within contracting and ship production process.

3 Methodology for the ship exploitation feedback implementation towards Improving the ship design and production process

In this chapter, the authors have described the suggested methodology procedure which is organised in four phases, as shown on Figure 1.

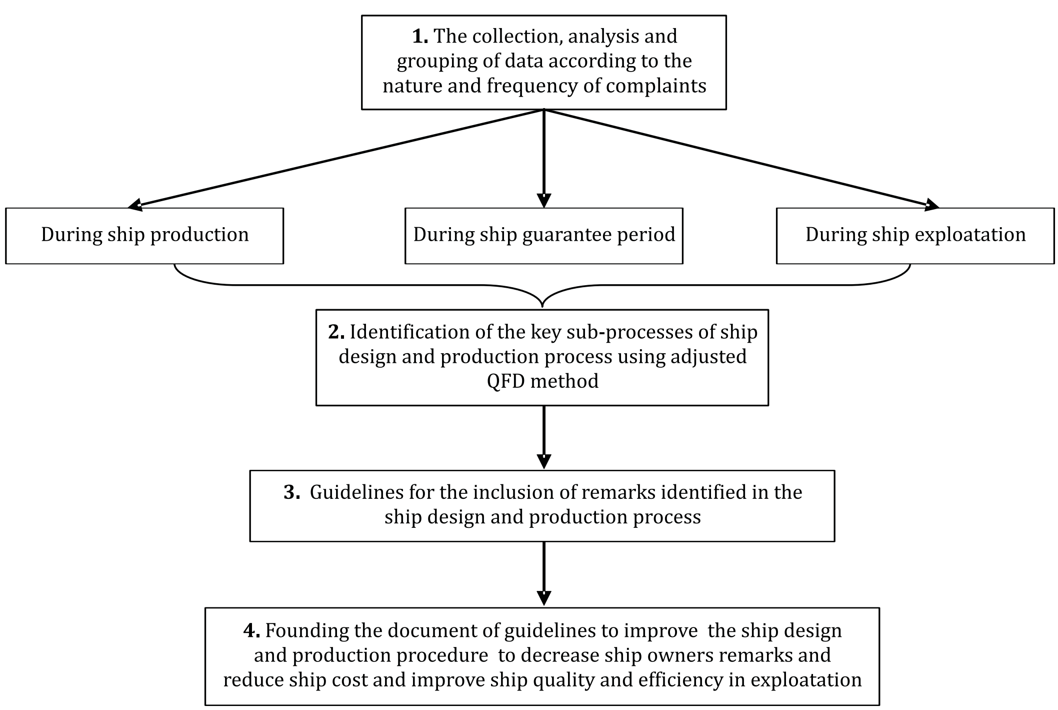

Figure 1 Phases of the proposed methodology for the improvement of ship design and production process of outfitting based on remarks and feedback information from the shipowner

3.1 The collection, analysis and grouping of data according to the nature and frequency of complaints

The data collection phase is the first within the proposed methodology and it is very important, because it represents the input to the next phase of the proposed methodology. It takes a significant amount of data collected feedback/remarks to identify the critical positions in the process of ship design and production concerning the ship functionality in exploitation, in maintenance and repair. Therefore, at this stage, it is important to collect accurate and precise feedback information from several shipowners and for the different types of ships. Therefore, an expert approach using the survey, interviewing, as well as the use of relevant documents such as forms and Remarks Guarantee Claim Form is proposed. In this paper and for the purpose of verification methodology to the real-world example, the return data are collected on the basis of five asphalt carriers' type ships. Following the proposed methodology, related documents such as Remarks Form during the construction of the ship, Guarantee Claim Form from ship exploitation, and additional empirical data obtained by interviewing the shipowner and interviews of selected members of the crew have been analysed. Feedback remarks have been statistically analysed and grouped according to the type of problems and by its occurring frequency. List of species problems with their description and features, and the percentage of representation are given in Table 1.

Table 1 Grouped Remarks Percentage

Group	Description	Percentage
Approach	Remarks regarding the access to the workplace, equipment, devices and instruments	7.2 %
Accessibility	Remarks regarding the accessibility and obstruction during the movement of the crew through the ship	9.3 %
Damages	Damage as a result of works during ship outfitting	1.8 %
Documentation	Defects regarding outfitting and equipment caused by deficiencies or mistakes in the documentation	**19.0 %**
Functionality	Errors caused by poor design solutions	2.1 %
Defects in assembly	Defects as results of errors in ship equipment assembly	**28.6 %**
Maintenance	Remarks regarding poor solution concerning ship maintenance	5.4 %
Good shipbuilding practice	Remarks regarding noncompliance to the good shipbuilding and seamen practice in terms of working and living on board a ship.	**26.4 %**
Total		**100 %**

Most of the remarks are in the field of defects in the documentation and assembly and in the field of good shipbuilding practices. Further remarks are regarding ease of approach, accessibility, maintenance and functionality. Thereby, remarks in the field of functionality, documentation, approach and accessibility can be affected by the intervention in documentation, and they are generally significantly lower in vessels in series, but in most of the other can be influenced primarily by raising levels of experiential knowledge of shipbuilders, which can be improved by in this paper suggested methodology. In addition, the way of dealing with such complaints is normally based on the assessment of "on the spot" and remarks that can be easily and cheaply removed, solved immediately, and for more complex remarks, that require additional material, time and higher costs, requires the approval of the responsible experts from shipyards which then generally takes longer time and disturbs the normal flow of production. It is in best interest of the shipyard that there are fewer remarks in the later production stages and ship guarantee period. Therefore the shipyard is interested in locating the most important sub processes which influence the occurrence of remarks the most, and then improves those processes. For that matter, the authors use the adjusted QFD methods to accurately identify critical places in the ship design and production process and sub processes on which one should primarily act.

3.2 Identification of the key sub-processes of ship design and production process using adjusted QFD method

The Quality Function Deployment (QFD) method was developed at the Kobe Shipyard of Mitsubishi Heavy Industries, Ltd., and has evolved considerably since then. QFD facilitates translation of a prioritized set of subjective customer requirements into a set of system-level requirements during system conceptual design. A similar approach may be used to subsequently translate system-level requirements into a more detailed set of requirements at each stage of the design and development process. Quality Function Deployment (QFD), [5], is used as a structured approach for defining the shipowner needs and remarks and translating them into specific locations within shipyards sup-processes where the additional quality control is required to meet those needs. The shipowner remarks are captured in a variety of ways, directly or indirectly, [6]. This understanding of the shipowner remarks and needs is then summarized in a product planning matrix. These matrices are used to translate a higher level of needs into a lower level of product requirements, or technical characteristics. In such a manner, using this method, the general characteristics of the product are determined, as premises towards generating the higher level of ship production process, [7]. The shipowner's requirements or specific technical characteristics and the product specification serve as the basis for developing product concepts. Product benchmarking, brainstorming, and research and development are sources for new product concepts. The applied QFD method was adjusted in the way that collected input data, derived from the previous analysis (regarding remarks frequency of occurrence), and were used as weighting factors in the process of identifying the shipyards key sub-processes. Factors used are shown in Table 2.

Table 2 Weight factors

Category	Interval	Weight factor
Strong impact (S)	>10%	5
Medium impact (M)	5 – 10 %	3
Week impact (W)	<5%	1

Note: The weight factors 2 and 4 are used as intermediate values.

The basic Quality Function Deployment technique involves four phases that occur over the course of the ship development process. During each phase, one or more matrices are prepared to help plan and communicate critical product and process planning and design information.

Once the shipowners requirements are identified, the product planning matrix is generated, Table 3.

Calculation of weight factors based on shipowner requirements in Table 3 is performed using the following equation:

$$CWF_1 = \sum_{i=1}^{n} N_i \times W_i \tag{1}$$

where is:

- CWF_1 – calculated weight factor based on shipowners requirements
- N_i – *i*-th column,
- W_i – *i-th* weight factor based on frequency.

Solving product planning matrix using weight factors by equation (1), the most influenced product characteristics by costumer requirements, from table 1 are detected. The three most important are shown in different colours, respectively columns *F*, *G* and *H*.

Quality Function Deployment continues this translation and planning into the process design phase. A product concept selection matrix can be used to evaluate different manufacturing process locations and to select the most influenced ones. Process planning matrix shown is created and shown on Table 4. The calculated weight factor based on shipowner requirements was normalized to obtain weight factors which were introduced within column NW.

Calculation of weight factors based on functional product characteristics in table 4 is calculated using the following equation:

$$CWF_2 = \sum_{i=1}^{n} N_i \times NW_i \tag{2}$$

where is:

- CWF_2 – calculated weight factor based on functional product characteristics,
- N_i – *i-th* column,
- NW_i – *i-th normalized* weight factor based on ship owners requirements.

Solving product planning matrix using weight factors by equation (2), the most influenced process characteristics from Table 4 are detected. The three most important are shown in different colours, respectively columns *B*, *E* and *A*. Important processes and tooling requirements can be identified to focus efforts to control, improve and upgrade processes and equipment. At this stage, communication between engineering and manufacturing is emphasized and trade-offs can be made as appropriate to achieve mutual goals based on the shipowner needs.

A Sub-process planning matrix is developed next. In the first column, process characteristics are included, while in the first row, sub-process characteristics are included too. Mutual interactions are validated using weight factors.

Calculation of weight factors based on process characteristics in Table 5 is performed using the following equation:

$$CWF_3 = \sum_{i=1}^{n} N_i \times NW_i \tag{3}$$

where is:

- CWF_3 – calculated weight factor based on process characteristics,
- N_i – *i-th* column,
- NW_i – *i-th normalized* weight factor based on ship owners requirements.

Table 3 Product planning matrix

Functional product characteristics / Customer requirements	Dimensions	Ergonomy	Deadweight	Speed	Autonomy	Production cost	Production time	Exploatation cost	**Weight factor based on frequency**
N=	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**W**
Approach	5	5	1	1	1	1	1	5	**3**
Accesibility	1	5	1	1	1	1	1	5	**3**
Damages	0	0	0	0	0	5	5	1	**1**
Documentation	0	1	0	0	0	5	5	1	**5**
Functionality	0	0	0	0	0	5	5	5	**1**
Defects in assembly	0	0	0	0	0	5	5	5	**5**
Maintenance	0	0	0	0	0	5	0	5	**3**
Good shipbuilding practice	0	3	0	3	3	3	5	5	**5**
Calculated weight factor based on shipowners requirements (CWF_1)	**18**	**50**	**6**	**21**	**21**	**96**	**91**	**106**	21,2

Table 4 Process design matrix

Process characteristics / Functional product characteristics	Contracting	Preparation	Construction	Equipment	Painting process	Delivery	Normalised weight factor based on customer requirements
N=	**A**	**B**	**C**	**D**	**E**	**F**	**NW**
Dimensions	3	1	3	5	5	1	**1**
Ergonomy	3	3	1	3	5	1	**2**
Deadweight	3	5	1	0	0	0	**0**
Speed	3	5	1	0	0	0	**1**
Autonomy	3	5	1	0	0	3	**1**
Production cost	5	3	5	5	5	1	**5**
Production time	1	3	5	5	5	1	**4**
Exploitation cost	3	5	1	0	0	0	**5**
Calculated weight factor based on functional product characteristics (CWF_2)	**58**	**71**	**56**	**55**	**60**	**15**	14,14

Table 5 Sub-process design matrix

Sub-process characteristics / Process characteristics	Bid	Production documentation	Fabrication	Subassembly	Berth	Outfitting in sections/ blocks	Outfitting on board a ship	Painting in workshop	Painting on board a ship	Ship trial	Normalised weight factor based on customer requirements
N=	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**NW**
Contracting	5	3	0	0	0	0	0	0	0	1	**4**
Preparation	5	5	3	5	5	5	1	3	1	0	**5**
Construction	1	5	5	5	5	5	5	3	3	0	**4**
Equipment	0	5	1	3	3	5	5	1	3	1	**4**
Painting process	0	5	0	1	3	3	3	5	5	0	**4**
Delivery	0	0	1	1	1	3	1	3	1	5	**1**
Calculated weight factor based on process characteristics (CWF_3)	**50**	**98**	**40**	**62**	**70**	**80**	**58**	**55**	**51**	**13**	19,6

Solving product planning matrix using weight factors by equation (3), finally the most influenced sub-process characteristics from Table 5 are detected (regarding Table 1). The most important sub-processes are shown in different colours, and all the sub-processes can be ranked by importance (Table 6) with the related normalized weight factor.

Table 6 Ranking of the most influenced sub-processes for solving shipowner's requirements

Rank	Sub-process	Normalised weight factor
1	Production documentation	5
2	Outfitting in sections/blocks	4
3	Berth	4
4	Subasseembly	3
5	Outfitting on board a ship	3

Table 7 Sub-process/Quality control matrix

Rank	Sub-process	Control parameters	Control points	Control methods	Control frequency
1	Production documentation	Completeness, precision	Gantogram milestones	Visual, classification	According to building strategy
2	Outfitting in sections/blocks	Dimensions, precision, completeness, documentation	Workshop	Visual, dimensional, other relevant control methods	Within section delivery
3	Berth	Dimensions, precision, tolerance	Berth and ship	Visual, dimensional, other relevant control methods	Within block delivery
4	Subassembly	Dimensions, precision, completeness, documentation	Workshop	Visual, dimensional, other relevant control methods	After major production phases
5	Outfitting on board a ship	Completeness, functionality	Ship	Visual, testing, other relevant control methods	All equipment

Interventions, primarily within these sub-processes, shown in table 6, will directly result in solving most shipowner requirements. For that manner, the sub-process quality control matrix is developed in addition to determine the quality control tools and positions, Table 7.

3.3 Guidelines for the inclusion of remarks identified in the ship design and production process

As to collected, analysed and grouped remarks could be used on identified key sub processes to improve ship design and production process the following proposed guidelines should be followed:

– Improve ship design rules and procedures;
– Improve production procedures and rules;
– Improve quality control procedures;
– More detailed work instruction should be created;
– More precise and detailed procedures for negotiation process should be defined regarding remarks issues;
– Define procedures for familiarizing the shipowner with shipyard procedures, standards and appliance of ship exploitation experience, which will be used in the early negotiation stage in order to decrease level of remarks in later stages.

3.4 Founding the document of guidelines to improve the ship design and production process to decrease shipowner remarks and reduce ship cost and improve ship quality and efficiency

Finally, a detailed document should be generated to be used within shipyard practice and ship- owner information, and it should include:

– Detailed guideline description;
– Guideline field of application;
– Responsibility issues regarding guideline application;
– Detailed procedures for guideline strategy of application;
– Guideline application control.

Such document would be implemented in the negotiations and contract documents and would be binding for the shipyard, and accepted by the shipowner. Such document would reduce the possibility of misunderstandings and the number of remarks during the ship production. If the document guidelines would not be accepted, shipowner has the possibility of amendments to the guidelines to suit their specific requirements for a particular ship.

4 Examples of guidelines implementation

To create a typical example of the implementation of guidelines for improving the ship design and production process in order to increase the level of handling and maintenance of the ship during the exploitation, the authors have taken into account the chain of operating and handling activities which includes the following factors:

– Operator (crew);
– Equipment (part, device, location...);
– Operator activity in handling, maintenance or repair.

With the combination of these three factors, the main guidelines and rules for the application of good shipbuilding and maritime practice in the design and construction of the ship are defined and consist of the following:

– Shortening the time required to perform work activities in operation, management and maintenance of ship equipment in operation;
– Reducing the impact hazard and risk in handling, management and maintenance of ship equipment in service.

Furthermore, each element in the chain of operating and handling activities should be joined with the appropriate above-mentioned rule. In this way, the matrix design strategies is created as to increase the level of handling and maintenance of the ship in operation, from which the detailed guidelines can be developed and used during the design and production of the ship. An example of such a matrix is shown in Table 8. It should be stressed once more that the proposed guidelines are as a rule in

Table 8 Example of guidelines for ship design and production process to achieve better ship handling and maintenance

basic design guidelines for improving production process for reduction of remarks concerning the maintenance of the ship in service		Main groups of activities		
		For handling	**For operating**	**Operation within ship areas**
Shortening the time required to perform work activities in operation, management and maintenance of a ship in exploitation	Relocation of work activities performed in high-risk areas ship	Automation of work activities in the management and maintenance of the ship	Remote control operating activities in the management and maintenance of the ship	Accommodation or move equipment to the lower risk area
	Shortening the time spent in hazardous areas of the ship		Automation and grouping of similar or same type of activities	Raising the level of handling and simplify maintenance in hazardous areas ship
Reducing the impact hazard and risk in handling, management and maintenance of ship equipment in operation	Moving danger sources from hazardous areas on ship			Delaying the request. maintenance and repair of equipment
	Reducing the impact of hazardous sources in hazardous areas ship		Moving handling operation and maintenance to the ship areas with a lower level of risk	Amendment properties of equipment located in hazardous areas ship

some form included in the relevant regulations of classification societies, SOLAS and IMO conventions, and rules and regulations of the national authorities, but this information is not sufficiently systematized. Therefore, the authors recommend the collection and integration of vast experience from good shipbuilding and maritime practices in specific guidelines, which ultimately can be applied as new rules for the ship design as well as instructions for the outfitting.

5 Expected results and discussion

By using the suggested methodology, the document of the proposed guidelines with control mechanisms and its application within ship design and production process the following improvements are expected:

- Raised level of knowledge and expertise of shipbuilders which is more adapted to the needs of the crew regarding the operation, maintenance and comfort of work and stay on board a ship;
- Reducing the costs of additional works, repairs and modifications and with less remarks at a later stage of ship production;
- Reducing the number of “conflict” situation between shipping companies and shipyards in the process of resolving remarks;
- Better negotiating position for shipyard regarding defining payment conditions of additional works;
- In early contracting phase, guidelines document provides the shipowner with a guaranteed level of design solution regarding building in good shipbuilding and maritime practices related to functionality, maintenance, safety and pleasure of staying on board a ship. On that basis, it is also expected to achieve a better price and contract conditions for a shipyard.
- When contracting, the shipowner would have the option to choose the level of the guideline implementation as well as recommending custom amendments, which would be further incorporated into all relevant documentation.

6 Conclusion

Shipyards are generally reserved regarding feedback data arising from ship exploitation due to less knowledge of the seaman profession conditions on board a ship in service. In this regard, the authors want to emphasize that it is necessary to improve the process of ship design and production process especially in outfitting, in order to minimize remarks of the shipowner in the later stages of construction of the ship and the warranty period, which are generally the most expensive for the shipyard. Moreover, Croatian shipbuilding market is aimed to so-called niche of customized ships with higher added value for a comparative advantage over competition from the Far East. So, the importance of investment in knowledge to build ships that would be more adapted to the seafarer from the standpoint of effective use, maintenance, security, aesthetics and comfort of work and life on board a ship is economically very significant.

For that matter, the authors have proposed a methodology for the ship exploitation feedback implementation towards improving the ship design and production process based on adjusted QFD method to reduce costs and improve ship efficiency in exploitation. The complex analysis was performed for the evaluation of shipowner remarks to get the best possible imputes parameters. Adjusted QFD method is used for the identification of key shipbuilding processes, regarding their influence on collected remarks, which should be primarily improved to reach targeted ship characteristics regarding mostly, in this research, the outfitting and equipment issues. Guidelines for conducting such improvement are defined and example presented. Applying the proposed methodology and the resulting document guidelines will result in a final product better adapted to the specific requirements of the ship in service, and with a reduced cost for the shipyard due to better contracting conditions and fewer shipowner remarks modifications in the later stage of the production process.

As a continuation of the research, the authors have proposed an extension of the document guidelines regarding the structure of the ship and in even greater measure to include the issues of the ship and crew safety. Furthermore, the authors have suggested that the shipyard should assign an expert with the task to monitor the conduct of the ship in service during the guarantee period, with the aim of detecting defects and problems and proposing better solutions that would be incorporated in the design of the next series of the same or similar ships which would further raise the quality of the final product.

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