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ORIGINAL RESEARCH

Real-time planning and monitoring of the steel pipes towards life cycle sustainability management

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Abstract

The present study covers the possibilities of computer CAD (solid) design for the development of ASTM A36 Steel and DIN Steel (Alloyed) 1.6587 (18CrNiMo7-6) pipes, applying environmental and technical standards. The models are developed using SolidWorks Software which provides the ability to study the three-dimensional geometry of environmental friendliness through the specialized application Sustainability based on life cycle assessment (LCA). In real time, the models are tested for resilience in a computer environment, and data on environmental impact are obtained containing values of carbon footprint, energy consumption, air acidification and water eutrophication. The analysis includes data on material, manufacturing, use and end of life. The process of obtaining the data of mass properties of the three-dimensional geometry at the stage of computer 3D design is automated. A logistics plan is made through the selection of regional and transport principles. The present study gives a thorough overview how to apply modern technical means to optimize the concept of design—environmental friendliness—logistics.

Keywords Sustainability · SolidWorks · Eco standards · Environmental impact · Steel pipes

Abbreviations

ASM	American society for metals
CAD	Computer aided design
EMS	Environmental management Systems
ESW	Ecodesign strategy wheel
ISO	International organization for standardization
LCA	Life cycle assessment

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1 Introduction

The concept of Sustainable design is a global formulation of many design processes, including a number of divisions, sections, connections and all kinds of links related to the development of custom models. Sustainable design is based on solid and clear principles, while at the same time being in a constant evolutionary process, which is consistent with new approaches, environmental factors, technological development and others (Ceschin and Gaziulusoy, 2016; Crul et al., 2006; White et al., 2008) . They may be related to product design (Chaudhary et al., 2014; Clark et al., 2009; Fernandes and Canciglieri, 2014; Huang et al., 2016) , architecture (Kim and Rigdon, 1998; Lacroix and Stamatiou, 2007; Tomasowa, 2018) , textile industry (Angharad, 2008) , the construction of transport equipment and facilities (Cioca et al., 2019; Gaudillat et al., 2017; Mayyas et al., 2016; Medina and Naveiro, 2003; Vaz et al., 2017) and others (Skerlos et al., 2006) . Sustainability represents a balanced interaction between the human-built and natural worlds and includes three components: environment, social equity, and economy. Referring to the environment we have to take into consideration natural resources that are in material - energy symbiosis. However, it has to be emphasised that ecological environment provides a set of resources that are to one degree or another better than in the region where the system is located, to which the country or region seeks to optimize sustainbly. Furthermore, the environment is often associated with the direct link between nature and human health and the other local biological species (Dorokhina and Panteleev, 2012; Ruggles et al., 2014) . On the other hand, social equity is directly oriented towards people and in turn they are responsible for society, the environment, including environmental protection and biodiversity. This component is very much related to the economy in terms of law enforcement and justice for all. All the highly moral and virtuous values are included here (Eizenberg and Jabareen, 2017) . Economy supports and provides management of the production, consumption and distribution of goods and services produced by people. It is a complex system itself that must be organized in a balanced way within the local environment. It has to provide the necessary financial conditions for a quality life of the locals in accordance with the overall vision of the region in which the respective country is located (Curtis and Lehner, 2019) .

The three components—environment, social equity, and economy, in addition to being in constant dependence, they are characterized by the fact that they need to be in a state of harmony. This is especially important because the occurrence of certain negative conditions and events can lead to a violation of sustainability. Therefore, it is accepted that sustainability is perceived as a system constructed on the basis of three pillars (Purvis et al., 2019) . In Fig. 1, it is possible to see the aspect mentioned above.

When it comes to business, companies must also strive for sustainability. This is a complex process that is in a certain dynamic state, which with global problems quickly passes from one form to another. Good management of business-oriented companies must have a clear vision of the changes taking place and be able to optimize its policy in real time. The structure of sustainable companies often consists of (Ruggles et al., 2014) :

- **Strategy:** The global world puts companies in a competitive position. This leads to certain challenges related to the development of the region / regions, policy, logistics capabilities, technological development, ICT, product life cycles and processes, new materials and increased consumption (Parcheva, 2014, 2016) .
- **Logistics & supply chain:** The parallel rapid development of globalization processes is crucial in the creation of new forms of communication, the construction of logistics corridors, alternative transport opportunities, timely decision-making adequate to open

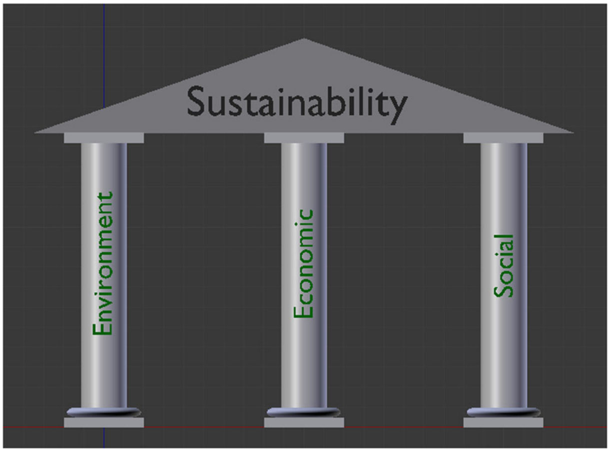


Fig. 1 Sustainability concept and its main pillars

borders and direct negotiation between all units ensuring the supply of resources and products (Milovanović et al., 2017) .

- **Efficiency & implementation of standards:** Management and eco-standards are in direct collaboration, which requires the implementation, compliance and adherence with internationally accepted standards. Thus, leading companies have implemented Environmental Management Systems (EMS). The concept of sustainable design adopts the standard ISO standard (ISO 14001:2015) governing EMS, as well as the International Organization for Standardization ISO 14040 and ISO 14044 Environmental management Life cycle assessment (LCA) (Koffler et al., 2020; Muller et al., 2014) .
- **Product development & design:** Based on sustainability, successful companies are in a constant process of optimizing the stages of product design development. This refers to the initial idea, technical sketch and drawing with subsequent development in a computer environment, data transfer to one or another compatible system, implementation of the final product. In the process of product design development it is necessary to set forecasts and calculations covering the product life cycle and where possible to implement "green" concepts, operating principles, environmental protection, occupational safety, etc. (Guo, 2017) .

Referring to the product design, it is good and advisable to look for new opportunities to optimize the overall concept through the introduction of modern technological means. It appears that in order to manage the complexity of designing products a key factor becomes material (McDowell et al., 2010) . Its reduction and diversification facilitates to achieve a sustainable future (Sharif Ullah et al., 2014) , however, assessing the appropriateness of materials is not an easy task and may lead to a certain degree of uncertainty. For example, the CAD system SolidWorks can be applied as a tool, which makes it possible to calculate mass properties and sustainability in accordance with environmental impact:

- Carbon footprint CO_2
- Water eutrophication PO_4
- Air acidification SO_2
- Total energy consumed MJ

Fig. 2 Ecodesign strategy wheel (ESW) (Brezet and van Hamel, 1997; Chulvi and Vidal, 2011)

In order to solve the described problem in this paper eco-sustainable parameters are obtained on the basis of the developed models of pipes. The achieved results are described in details, as well as supported by visual data, and tested for resilience. Thus, the main contribution of the paper is:

- Development of 3D models of steel pipes based on environmental and technical standards;
- Development of the methodology of testing models under predefined conditions;
- Effectiveness verification with the application of two types of pipes: ASTM A36 Steel and DIN Steel (Alloyed) 1.6587 (18CrNiMo7-6) Pipes;
- Elaboration of logistic plan for exemplary products based on manufacturing and use region, and transport.

The paper is organized as follows: Sect. 2 focuses on the description of the physical model of steel pipes which is used during the research. It also shows the procedure of developing models through the SolidWorks software. Section 3 illustrates two examples of the application of the proposed approach. Finally, Sect. 4 presents discussion and Sect. 5 concludes the paper.

2 Materials and methods

In order to obtain as much data as possible about the values, parameters and characteristics of the product we referred to the sustainability of the system as a whole. It allows for broader view and greater control in predicting the life cycle of the product as shown in Fig. 2.

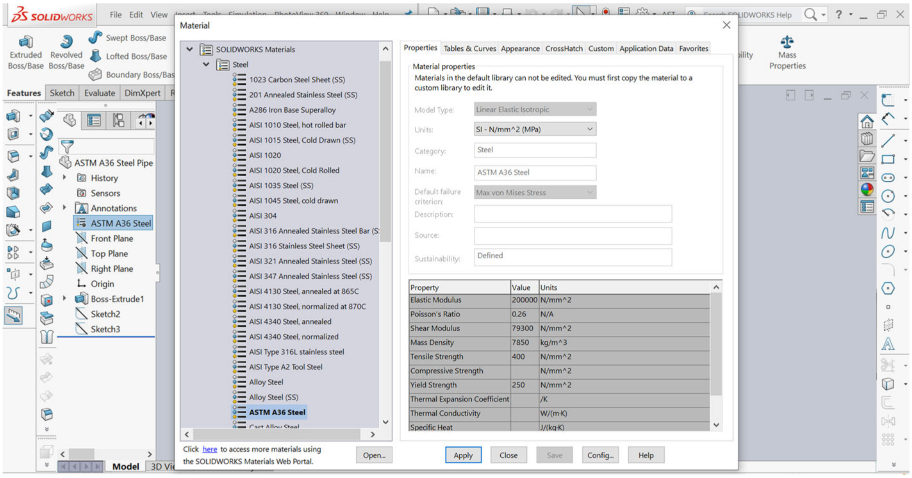
Figure 2 shows an extension of the manual published by the United Nations Environmental Programme (UNEP) in 1997, which was based on the Dutch manual "Promise" (Brezet et al., 1994) . It refers to the primary research results where 33 ecodesign strategies for the development of environmental friendly products were identified and classified into 7 groups so-called “Ecodesign Strategy Wheel” (van Hemel and Cramer, 2002) . It provides a basic framework that can be used systematically to review the entire life cycle of a product. Following it, in order to optimize the product’s performance, it is clearly visible that there must be kept a balance of functional, economic and environmental elements. ESW begins with a new product concept, and it covers design, materials selection, production, distribution, and the use and end of a product’s life. These strategies should be perceived as guidelines for designers who should consider them when developing environmental friendly products. However, the practice shows that some companies use them to be more focucused on the development of environmental friendly products while the others are more concerned on the utilization of ecodesign at strategic level or even make one step further and shift to eco-innovations where the attention is paid to economical point of view (Cluzel et al., 2014) .

In our research we developed 3D models/products through the SolidWorks software. This system combines precision of the design process at each stage of construction and subsequent analysis for quality control and data retrieval. SolidWorks is supported and developed by Desault Systemes, as the system began in the 90’s as a strict CAD system specializing in product design, then began integrated (via Plug-ins) and hybrid interaction with other technical means to increase capacity and the capabilities of the program oriented directly to CIM systems (Balabanova et al., 2016; Gattamelata et al., 2006; Li et al., 2009; Rehman et al., 2018; Hyun, 2012) . The software uses the CML methodology, developed by the Institute of Environmental Sciences at the University of Leiden in the Netherlands. It refers primarily European data to derive its impact factors and groups the LCI results into categories.

In the present study, the data rely on the standardized parameters of American Society for Metals (ASM) (Davis et al., 1998) . They are input data for ASTM A36139Steel and DIN Steel (Alloyed) 1.6587 (18CrNiMo7-6). On the basis of them the samples of metal pipe profiles made of ASTM A36 Steel and DIN Steel (Alloyed) 1.6587 (18CrNiMo7-6) materials are developed (Standard ASTM, 2019) . They are computer solidly constructed in the environment of SolidWorks CAD system. The physical properties of both materials are shown visually in the way it is present in its original form in SolidWorks / material database MetalPrices / Material Financial Impact data based on bulk raw material price computed from MetalPrices.com which use official data of American Society for Metals (ASM) (MetalPrices, 2012) . Figures 3 and 4 show selected SolidWorks base material ASTM A36 Steel and DIN Steel (Alloyed) 1.6587 (18CrNiMo7-6) and their properties such as: Elastic Modules, Poisson’s Ratio, Shear Modulus, Mass Density, Yield Strength. It is important to specify that the SolidWorks system recommends not to change the standardized values of the selected material “Materials in the default library cannot be edited”, allowing for editing in the custom library.

3 Results

The 3D models are developed individually in three different types distinguished in outher diameter and length, while thickness and inside diameter were preserved. Then, the pipes are grouped in Assembly. The technical requirements and parameters of Global Sources (2020) are complied with (Global Sources, 2017) . Three types of steel pipes with dimensions defined in Table 1 are solidly constructed.



Click here to access more materials using the SOLIDWORKS Materials Web Portal.

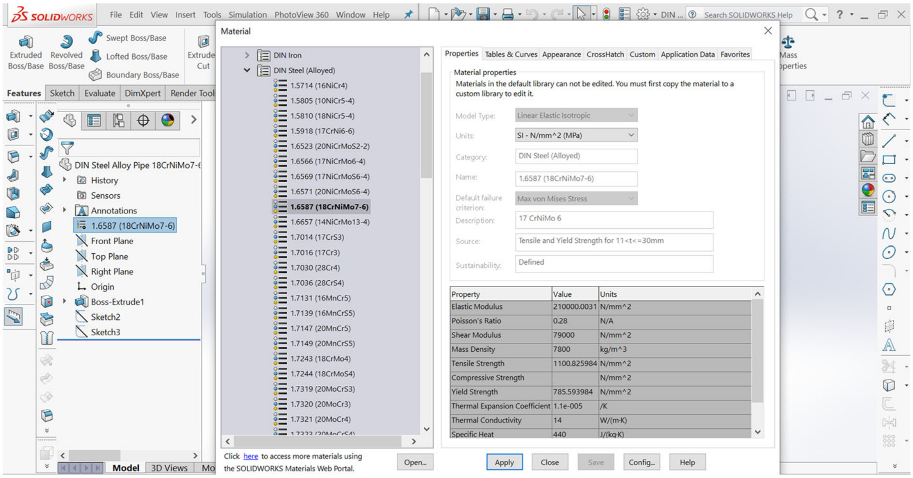
Material properties

Materials in the default library can not be edited. You must first copy the material to a custom library to edit it.

Model Type: Linear Elastic Isotropic
Units: SI - N/mm^2 (MPa)
Category: Steel
Name: ASTM A36 Steel
Default failure criterion: Max von Mises Stress
Description:
Source:
Sustainability: Defined

Property	Value	Units
Elastic Modulus	200000	N/mm^2
Poisson's Ratio	0.26	N/A
Shear Modulus	79300	N/mm^2
Mass Density	7850	kg/m^3
Tensile Strength	400	N/mm^2
Compressive Strength		N/mm^2
Yield Strength	250	N/mm^2
Thermal Expansion Coefficient		/K
Thermal Conductivity		W/(m·K)
Specific Heat		J/(kg·K)

Fig. 3 SolidWorks base material: ASTM A36 Steel



Click here to access more materials using the SOLIDWORKS Materials Web Portal.

Material properties

Materials in the default library can not be edited. You must first copy the material to a custom library to edit it.

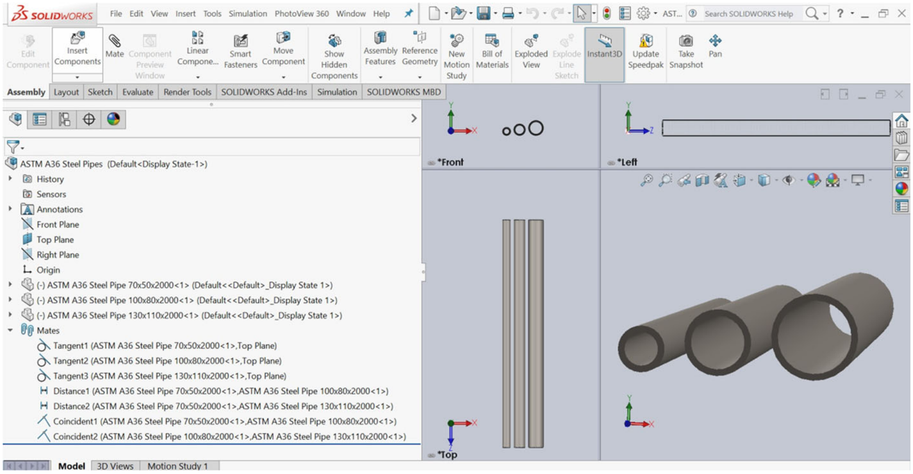
Model Type: Linear Elastic Isotropic
Units: SI - N/mm^2 (MPa)
Category: DIN Steel (Alloyed)
Name: 1.6587 (18CrNiMo7-6)
Default failure criterion: Max von Mises Stress
Description: 17 CrNiMo 6
Source: Tensile and Yield Strength for 11<t<=30mm
Sustainability: Defined

Property	Value	Units
Elastic Modulus	210000.0031	N/mm^2
Poisson's Ratio	0.28	N/A
Shear Modulus	79000	N/mm^2
Mass Density	7800	kg/m^3
Tensile Strength	1100.825984	N/mm^2
Compressive Strength		N/mm^2
Yield Strength	785.593984	N/mm^2
Thermal Expansion Coefficient	1.1e-005	/K
Thermal Conductivity	14	W/(m·K)
Specific Heat	440	J/(kg·K)

Fig. 4 SolidWorks base material: DIN Steel (Alloyed) 1.6587 (18CrNiMo7-6)

Table 1 Solidly constructed models of Steel Pipes with the corresponding dimensions

Steel pipes Types	$Outerdiameter$ $[mm]$	$Innerdiameter$ $[mm]$	Thickness [mm]	Length [mm]
Type 1a - Small	70	50	10	2000
Type 1b - Small	70	50	10	3000
Type 1c - Small	70	50	10	5000
Type 2a - Medium	100	80	10	2000
Type 2b - Medium	100	80	10	3000
Type 2c - Medium	100	80	10	5000
Type 3a - Large	130	110	10	2000
Type 3b - Large	130	110	10	3000
Type 3c - Large	130	110	10	5000



```
ASTM A36 Steel Pipes (Default<Display State-1>)
  History
  Sensors
  Annotations
  Front Plane
  Top Plane
  Right Plane
  Origin
  (-) ASTM A36 Steel Pipe 70x50x2000<1> (Default<<Default>_Display State 1>)
  (-) ASTM A36 Steel Pipe 100x80x2000<1> (Default<<Default>_Display State 1>)
  (-) ASTM A36 Steel Pipe 130x110x2000<1> (Default<<Default>_Display State 1>)
  Mates
    Tangent1 (ASTM A36 Steel Pipe 70x50x2000<1>,Top Plane)
    Tangent2 (ASTM A36 Steel Pipe 100x80x2000<1>,Top Plane)
    Tangent3 (ASTM A36 Steel Pipe 130x110x2000<1>,Top Plane)
    Distance1 (ASTM A36 Steel Pipe 70x50x2000<1>,ASTM A36 Steel Pipe 100x80x2000<1>)
    Distance2 (ASTM A36 Steel Pipe 70x50x2000<1>,ASTM A36 Steel Pipe 130x110x2000<1>)
    Coincident1 (ASTM A36 Steel Pipe 70x50x2000<1>,ASTM A36 Steel Pipe 100x80x2000<1>)
    Coincident2 (ASTM A36 Steel Pipe 100x80x2000<1>,ASTM A36 Steel Pipe 130x110x2000<1>)
```

Fig. 5 Selected ASTM A36 Steel pipes (Types 1a, 2a, 3a) in a 3D SolidWorks CAD system environment

Figure 5 shows three smallest dimensional models of ASTM A36 Steel Pipes in basic projections, respectively: Type 1a, Type 2a, Type 3a, located in the environment of SolidWorks CAD system with generated material ASTM A36 Steel. The image gives an additional informational idea supporting the design process.

The precise three-dimensional geometry of the models allows for computer calculation of Mass Properties. The moments of inertia and products of inertia are calculated as follows:

$$\begin{aligned}
I_{xx} &= \int (y^2 + z^2)dm, \\
I_{yy} &= \int (z^2 + x^2)dm, \\
I_{zz} &= \int (x^2 + y^2)dm, \\
I_{xy} &= \int (xy)dm, \\
I_{yz} &= \int (yz)dm, \\
I_{zx} &= \int (zx)dm. \qquad (1)
\end{aligned}$$

The inertia tensor matrix is defined below from the moments of inertia: (2) from (Dassault Systemes SolidWorks, 2020) .

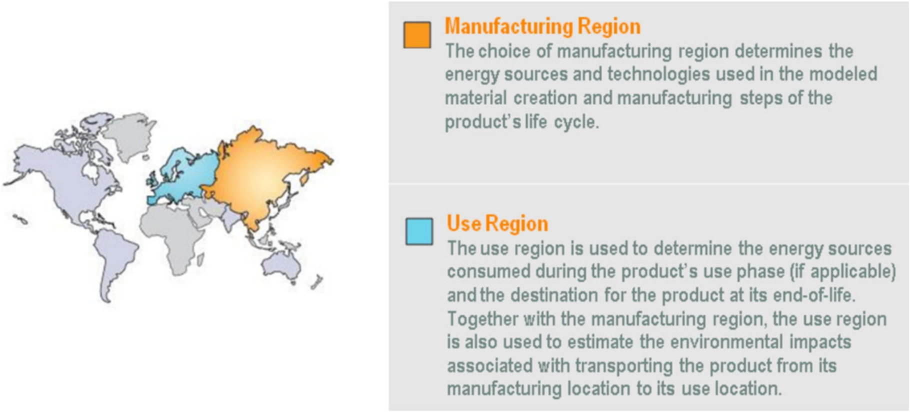
$$\begin{vmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{xy} & I_{yy} & -I_{yz} \\ -I_{xz} & -I_{yz} & I_{zz} \end{vmatrix} \qquad (2)$$

Table 2 shows SolidWorks CAD calculated Mass Properties of ASTM A36 Steel Pipes and DIN Steel Alloy Pipes 18CrNiMo7-6.

In order to comply with the Eco-norms, the samples are subjected to analysis through the specialized module integrated in SolidWorks - Sustainable Design (Popa and Popa, 2017) . Figure 6 shows Manufacturing & Use Region.

Table 2 SolidWorks CAD calculated Mass Properties of ASTM A36 Steel* and DIN Steel (Alloyed) 1.6587 (18CrNiMo7-6)** Pipes

Steel Pipes	SP: Small	SP: Medium	SP: Large
Mass properties/Types	T1a—T1b—T1c	T2a—T2b—T2c	T3a—T3b—T3c
Density [kg/cm^3]	0.01—0.01—0.01	0.01—0.01—0.01	0.01—0.01—0.01
Mass* [kg]	29.59—44.39—73.9	44.39—66.59—110.98	59.19—88.78—147.97
Mass** [kg]	29.41—44.11—73.51	44.11—66.16—110.27	58.81—88.22—147.03
Volume [cm^3]	3769—5654—9424	5654—8482—14137	7539—11309—18849
Surface area [cm^2]	7577—11347—18887	11366—17021—28330	15155—22694—37774



🟧 **Manufacturing Region**

The choice of manufacturing region determines the energy sources and technologies used in the modeled material creation and manufacturing steps of the product's life cycle.

🟦 **Use Region**

The use region is used to determine the energy sources consumed during the product's use phase (if applicable) and the destination for the product at its end-of-life. Together with the manufacturing region, the use region is also used to estimate the environmental impacts associated with transporting the product from its manufacturing location to its use location.

Fig. 6 Manufacturing Region (Asia) & Use Region (Europe). Built to last: 10 year and Duration of use: 10 year

The samples are subjected to research in a computer environment, and in real time (via the Internet), data are obtained for:

- Material/ASTM A36 Steel and and DIN Steel (Alloyed) 1.6587 (18CrNiMo7-6);
- Transportation and use;
- Manufacturing—default option;
- End of life.

Following the automated computer calculation, a report is prepared for Steel Pipe Type 1a, and the following results are obtained:

- Recycled content: 18 %
- Transportation/ship distance: 1.6E+4 km (16093 km)
- End of life: recycled: 25 %, Incinerated: 24 %, Landfill: 51 %
- Material financial impact: ASTM A36 Steel—13.50 USD and DIN Steel (Alloyed) 1.6587 (18CrNiMo7-6)—30.00 USD

Table 3 shows comparison of environment impact for Carbon Footprint, Total Energy Consumed, Air Acidification and Water Eutrophication of ASTM A36 Steel Pipe for three manufacturing processes: milled, machined sand casting and extrusion.
The results of the research show that the greatest amounts of carbon footprint, air acidification and water eutrophication are achieved for milled manufacturing process in comparison to

Table 3 Environmental impact of ASTM A36 Steel Pipe Type 1a (calculated using CML impact assessment methodology)

ASTM A36 Steel pipe	Carbon Footprint [$kg\ CO_2e$]	Total energy Consumed [MJ]	Air Acidification [$kg\ SO_2e$]	Water eutro-Phication [$kg\ PO_4e$]
Milled	**89**	**1000**	**0.363**	**0.088**
Material	59	740	0.169	0.067
Manufacturing	2.5	25	0.035	1.4E-3
Transportation	1.2	14	0.038	3.6E-3
End of life	27	250	0.120	0.016
Machined sand Casting	**87**	**1000**	**0.327**	**0.087**
Material	59	740	0.169	0.067
Manufacturing	0.00	0.00	0.00	0.00
Transportation	1.2	14	0.038	3.6E-3
End of life	27	250	0.120	0.016
Extrusion	**87**	**1000**	**0.330**	**0.087**
Material	59	740	0.169	0.067
Manufacturing	0.161	1.6	2.3E-3	8.8E-5
Transportation	1.2	14	0.038	3.6E-3
End of life	27	250	0.120	0.016

machined sand casting and extrusion of ASTM A36 Steel Pipe. The extrusion manufacturing process influences environment not significantly whereas the process of machined sand casting does not have additional environmental impact. For material, transportation and end of life the same amounts of the investigated parameters are obtained. However, it is very important to notice that for all these categories the end of life is the second biggest environmental threat, just after the material, while its manufacturing is not so harmfull in any of them. This situation could be explained when we refer to the data showing that at the end of life only 25 % of steel is recycled whereas 24 % is incinerated and 51 % is landfilled.

In Table 4there is shown comparison of environment impact for Carbon Footprint, Total Energy Consumed, Air Acidification and Water Eutrophication of DIN Steel Alloy Pipe (18CrNiMo7-6) Type 1a.

As it can be noticed the environmental impact of DIN Steel Pipe 18CrNiMo7-6 Type 1a is lower for machined sand casting and extrusion than milled process when we refer to water eutrophication. In the case of carbon footprint, total energy consumtion and air acidification the same results are calculated. However, manufacturing process—extrusion influences more water eutrophication than machined sand casting. Furthermore, it has to be underlined that in the case of this type of steel pipe it appears that for all categories manufacturing creates the biggest environmental threat, just after the material, while end of life is not so harmfull.

The results presented in Table 3 and 4 are obtained on the basis of the automatic calculation of values (as of the date of the survey) which SolidWorks performs in real time online. The significance of the differences in values between these two types of steel pipes is relative and rather informative. We have to underline that in this research we referred to the pipes which length is between 2000 and 5000 mm what is really small in comparison to the real systems. However, it shows the context of the application of modern technologies in design

Table 4 Environmental impact of DIN Steel Pipe 18CrNiMo7-6 Type 1a (calculated using CML impact assessment methodology)

DIN Steel pipe 18CrNiMo7-6	Carbon Footprint $[kg\ CO_2e]$	Total energy Consumed $[MJ]$	Air Acidification $[kg\ SO_2e]$	Water eutroPhication $[kg\ PO_4e]$
Milled	**230**	**2500**	**2.0**	**0.150**
Material	73	900	0.220	0.062
Manufacturing	130	1400	1.6	0.069
Transportation	1.1	14	0.038	3.6E-3
End of life	26	250	0.119	0.016
Machined sand	**230**	**2500**	**2.0**	**0.149**
Casting				
Material	73	900	0.220	0.062
Manufacturing	130	1400	1.6	0.067
Transportation	1.1	14	0.038	3.6E-3
End of life	26	250	0.119	0.016
Extrusion	**230**	**2500**	**2.0**	**0.149**
Material	73	900	0.220	0.062
Manufacturing	130	1400	1.6	0.068
Transportation	1.1	14	0.038	3.6E-3
End of life	26	250	0.119	0.016
Extrusion	**230**	**2500**	**2.0**	**0.149**
Material	73	900	0.220	0.062
Manufacturing	130	1400	1.6	0.068
Transportation	1.1	14	0.038	3.6E-3
End of life	26	250	0.119	0.016

and gives preliminary orientation and full clarity of the developed models in accordance with the ecological criteria.

4 Discussion

Sustainability in steel production is a global challenge due to the increasing concerns about global climate change. The major environmental concerns are gas emissions and energy consumptions (He et al., 2020; Nidheesh and Suresh Kumar, 2019) . Carbon dioxide emission from the steel industry is around 997 kg per ton of steel what constitutes 4–5 % global carbon dioxide emissions (Zhang et al., 2018) . However, it is worth to emphasize that carbon dioxide emission during steel production depends on the processes. In comparison to other technologies, steel scrap-electric arc furnace technology is the lowest carbon dioxide emission but this technology is limited due to the low accessibility of steel scrap (Nidheesh and Suresh Kumar, 2019) . Therefore, for example, under the European Ultra Low CO2 Steelmaking (ULCOS) program such efforts as blast furnace with top-gas recycling (TGR-BF), a new smelting reduction process (HIsarna), advanced direct reduction (ULCORED) and electrolysis of iron ore (ULCOWIN and ULCOLYSIS) are investigated (Quader et al., 2016)

. And the year before that, in 2015, at the Paris Climate Conference, the Chinese government promised to reduce CO2 emissions per unit GDP by 65% compared with 2005 levels by 2030 (Wang et al., 2018) . This fact is extremely important as China's steel industry is the second largest national emitter of CO2 after the power industry (Zhang et al., 2018) . Steel production requires also high energy as it is around 30% of total industrial energy consumption whereas the remaining 70% of the energy consumed is converted into various forms of waste heat and residual energy (He et al., 2020; Wang, 2017) . However, its deep analysis shows that the energy intensity of steel production depends on plant capacity utilization, different environmental requirements in each countries and energy and raw materials cost (Jose et al., 2017) . The ecological sustainability of steel pipes also involves the impact of acidification and eutrophication potential (Ajeena and Al-Madhhachi, 2020; Kocks and Kroop, 2018) . Kock and Kroops (Kocks and Kroop, 2018) analyzed holistic life cycle assessments within the framework of the preparation of environmental product declarations. In their investigation they used the GaBits ® model of the life cycle assessment for water line pipe. Their results showed that the production of the steel accounts for more than 80% of the emissions in most of the environmental categories in the manufacturing phase. In order to reduce environmental impacts, it is necessary to focus on material efficiency. The decrease of the use of steel strip is superior to the reduction of ancillary materials. For example, subject to the intended application, it is potential to reduce a wall thickness of pipe and thus save material through the use of high-strength starting materials.

In our paper, on the basis of the created three-dimensional geometry of the solid models of metal pipes, we obtained exact values of mass properties such as: Density, Mass, Volume and Surface area 1. The obtained data rely on the standardized parameters of American Society for Metals (ASM), which are directly integrated into the SolidWorks CAD system, as they are set as input data for ASTM A36 Steel and DIN Steel (Alloyed) 1.6587 (18CrNiMo7-6). These results allow to obtain accurate data on the mass of metal pipes which lead to the possibility of accurate calculation of material costs. Moreover, on the basis of such information it is possible to optimize the economic process associated with the proper management of the distribution of financial investment.

The sustainability calculations are based on the already defined materials: ASTM A36 Steel and DIN Steel (Alloyed) 1.6587 (18CrNiMo7-6) due to the direct connection of the system to the global online network, through the specialized module Sustainability. The obtained results are automatically generated by the calculation module of the program, and only the data for the periods are entered manually in working panels: Manufacturing Region (Asia) & Use Region (Europe)—Built to last:10 year and Duration of use: 10 year. Furthermore, logistical possibilities for transport are provided, and in our cases the computer system recommended sea transport. In real time, the system recommended the use of this type of transport in accordance with the geographical areas, as well as with the specific logistical features (Fig. 6. Furthermore, the detailed environmental impact data are applicable to the respective regions where it is necessary to ensure the necessary balance in terms of Carbon Footprint, Total Energy Consumed, Air Acidification and Water Eutrophication (Tables 3 and 4. As a result of the calculations made in the SolidWorks CAD system, the recommendations are obtained for finding alternative materials, regions of production, transport and other parameters. At the service of the user, financial values are received in accordance with the current period of the inquiry. On the basis of this, the calculations can be performed in order to find the optimal financial resource to ensure the application for production, mode of transport and other important parameters for the implementation of the entire life cycle of products. In details the results obtain such information as: Recycled content, Transportation and End of Life: Recycled, Incinerated and Landfill. The proposed approach is a working system with real results that can be diversified at any time by introducing various appropriate parameters depending on the specific needs.

Life cycle assessment using the LCA method supported by SolidWorks CAD system provides a quantitative assessment of the impact of a product on the environment throughout its life cycle, from the purchase of raw materials to the production, distribution, use, disposal and recycling of this product. It is visible that the obtained general stability data are fully recommended, in contrast to the technical calculations of the three-dimensional geometry of the metal pipes, where the data are specific. The accumulated information corresponds to the main goal—optimization of Material Financial Impact whereas the financial impact is only associated with the material. The mass of the model is multiplied by the financial impact unit (units of currency/units of mass). This main aspect leads to the global strategy of each company to optimize its economic business approach in accordance with environmental characteristics and standards. The obtained results present a comprehensive view of the planning and monitoring of the steel pipes towards sustainable life cycle.

5 Conclusions

In the present study, a sustainable system is presented to emphasize the importance of seeking opportunities for design in accordance with the environment, social equity and economy. ASTM A36 Steel and DIN Steel Alloy (18CrNiMo7-6) Pipes are created in 3D in a computer environment of SolidWorks CAD system. The results show that in the case of the first analysed steel pipe milled manufacturing process influences more carbon footprint, air acidification and water eutrophication than machined sand casting or extrusion whereas the environmental impact of the second pipe is lower for machined sand casting and extrusion than milled process when we refer to water eutrophication. Moreover, the influence of all categories shows different results for both steel pipes, as material and end of life are the most significant for the first type of pipe, and manufacturing is the greatest threat for the second one. These results indicate that the effectiveness of optimizing business and logistics capabilities by implementing parallel engineering design with computer systems supporting up-to-date information data, through which real-time planning and monitoring of the product life cycle is carried out qualitatively.

The results of the study provide all the information about the environmental data. They serve to support design decisions in the process of professional activity. The application of this methodology further justifies the behavior and decisions of designers, otherwise it is possible to make human mistakes in the process of calculating ecological environment. To date, no better modern ways of studying ecological environment in a virtual environment are known. It should be noted that the software used claims quality that is globally known. Only as a point of attention it can be noted that the system is directly dependent on the availability of access to the database in real time (via the Internet). This is a feature that needs to be confirmed periodically by all those involved in the maintenance of the environmental research system, which requires periodic ensuring the timeliness of resources.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest or competing interests.

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