Designing and modeling of grapple buckets

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Abstract: *The paper presents the process of automated designing and parametric modeling of grapple buckets using the CAD system. The presented grapple buckets are designed for bulk materials and they are part of the grapple construction. Grapples are installed on cranes, excavators and other specialized machines. A methodology has been developed that covers all stages of design – from the creation of 3D models of the parts, sub-assemblies and assemblies, to the generation of design documentation, using template files. The presented approach allows the creation of parametric models with multiple configurations, which cover different variants of the products. Using the presented methodology leads to a reduction in the volume of created documentation and optimizes the design process. Data management within a PDM system ensures centralized storage, actuality and accessibility of information.*

KEYWORDS*: GRAPPLE BUCKETS, GRAPPLES, CRANES, EXCAVATORS, METHODOLOGY, DEVELOPMENT, 3D MODELS, AUTOMATED DESIGNING, PARAMETRIC MODELING, CAD SYSTEM, TEMPLATE FILES, DESIGN DOCUMENTATION, PDM SYSTEM*

1. Introduction.

The paper introduces the process of developing grapple buckets with a CAD system. The parts, sub-assemblies and assembly of the bucket are parametrically designed.

Grapple buckets are designed for bulk materials and they are part of the grapple construction. The grapples are used for loading and unloading of various materials. They are mounted on cranes, truck cranes, scrap gondolas, light trucks, excavators and other specialized machines [1, 2].

Grapples are the structure consisting of Grapple buckets (Left and Right), a Central body, a Rotator and a Carrier. Through the buckets, the grapple grabs materials. The Left and Right buckets are attached on the Central body. The Rotator rotates the grapple during operation. The Carrier attach the grapple to the corresponding machine.

The grapple buckets are designed and developed with the SolidWorks CAD system [3]. Using the CAD systems significantly facilitates the process of developing the product. The design is performed in the three-dimensional space. 3D models of the parts, sub-assemblies and assemblies are developed. The process of creating the design documentation is automated by using template files.

2. Literature review.

2.1. Parametric modeling of products with a CAD system.

Creating 3D models is an important step in the product development process. 3D models can be used to create new design documentation. In 3D models of parts and assemblies, the additional information is set by attributes (users and systems ones). The information from the attributes can be used for documentation management with PDM system, as well as by other departments in a company with ERP system [3, 4, 5, 6].

Based on the 3D models, the technology for parts manufacturing is also developed – adding or removing holes, determining allowances for mechanical processing, pre-processing of certain surfaces, and others [7]. This requires the creation of new design and technological documentation to be used in production. The 3D models are used to create the cutting files for the parts, which are made of sheet metal.

Very often the product is divided into sub-assemblies which are pre-manufactured and then a fixture is used to assemble them into the final product [8].

The next steps are developing the necessary fixtures for assembling, welding, machining and control [9, 10].

This means that product design is a long process that is implemented in multiple stages. Each stage is characterized by its own specific features [11, 12, 13, 14, 15].

Parametric modeling is used when the designed products have many versions and varieties. A single 3D model is created, where different versions of the product are presented with configurations. This leads to a small amount of design documentation for each specific product. The accumulated big amount of documentation can cause many problems, for example – how to manage, organize, classify and archive the documentation; who has the right to change and update it; the documents should always be with the latest version; which other departments of the company have access to this documentation and the specialized information they are interested in [5, 6].

Parametric modeling reduces the time of the design process and increases its efficiency. Design automation is achieved, which means that designers do not have to redesign the product when there is a change in the dimensions of the model. Parametrically can be modeled dimensions of the model, geometric constructions in the model (*Features*), constraints between parts in an assembly (*Mates*), etc.

2.2. Design documentation management through PDM system. Application of ERP systems.

PDM (Product Data Management) systems are specialized software used to manage product data. The term "product data" means all information related to the product. PDM systems manage arrays of data and information necessary for the design, manufacture and assembling of the products, as well as for their maintenance. The functionalities of PDM systems have been improved and in addition to the Design and Engineering Departments, they are now used by other departments such as Supplies, Production and Maintenance. This means that PDM systems are developed to manage and control the huge volume of electronic data created by CAD/CAM/CAE systems.

In the PDM system, each configuration of the 3D model of the grapple bucket is entered as a separate product. The system automatically fills in the fields of the Product card, based on the information set in the bucket model with attributes for each configuration. If necessary, additional information can be entered manually in the item card.

PDM systems are used when there is a big amount of design, technological, production and other types of documentation accompanying the products that are developed, manufactured and supported. PDM systems solve the problems associated with the maintenance, storage and actuality of documentation related to the products [3].

ERP systems (Enterprise Resource Planning) are used in all processes necessary for the functioning of a company - people management, finances, production, availability of materials or products, supply system, services, orders, etc. One of the main functions of ERP systems is the shared database, i.e., the employees from different departments operate with the same information for their specific needs [4].

Both systems are part of the so-called Product Lifecycle Management (PLM). This means that a specific product is tracked from the creation of the product concept to the end of its life cycle.

3. Parametric modeling of the Grapple Buckets.
3.1. 3D models of the buckets.

The paper presents an approach to improve the efficiency of the product design process by using parametric modeling. The CAD system SolidWorks was used [3].

The SolidWorks CAD system enables parametric modeling through *parametric tables* or through *configurations*.

The paper discusses the parametric modeling approach using configurations. During modeling, configurations are created in 3D models of parts, sub-assemblies and assemblies.

Different models of grapple buckets differ in purpose, dimensions and construction. Fig. 1 shows the considered grapple bucket [1, 2].

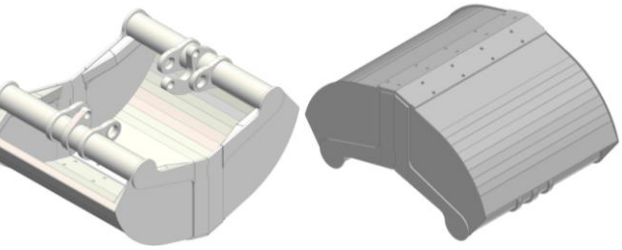
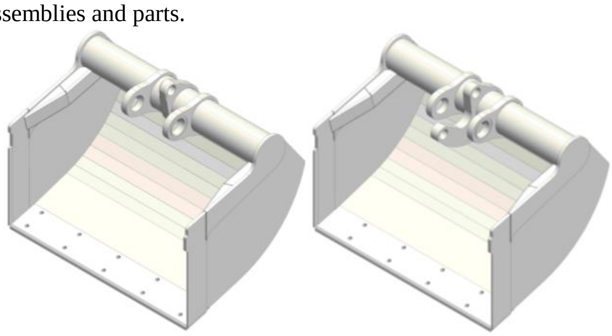


Fig. 1. *Grapple bucket 1000 mm.*

The grapple buckets of this model are three types, which differ in length – 640 mm (623016201), 800 mm (623016204) and 1000 mm (623016207).

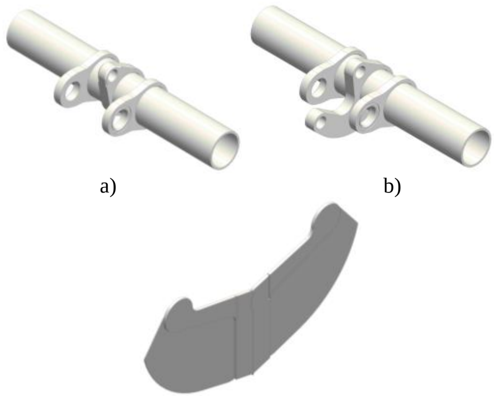
A set of grapple buckets (Left and Right) is manufactured for each grapple. Each of them consists of pre-assembled sub-assemblies and parts.



a) b)

Fig. 2. *Components of the Grapple Bucket 1000 mm.*
a) Left Bucket, b) Right Bucket

Fig. 3 shows the 3D models of the sub-assemblies from which the grapple buckets are made.



a) b) c)

Fig. 3. *Sub-assemblies of the Grapple Bucket 1000 mm.*
a) Left Tube, b) Right Tube, c) Bucket Side

Each of the parts from the sub-assemblies is developed by using different 3D modeling commands – *Extruded Boss/Base*, *Revolved Boss/Base*, *Extruded Cut*, *Revolved Cut*, etc. Parts that are made from sheet metal are created using the module *Sheet Metal*, in this way their unfolding is obtained. The parts are assembled into individual sub-assemblies, which are assembled into the assembly of the bucket [8, 9].

The development of 3D models is consistent with the manufacturing technology of the buckets, as well as with the possibility of using the models from the PDM and ERP systems.

A design methodology has been used in the development and modeling of the products with the SolidWorks CAD system. This makes the modeling process easier and reduces the time required for designing. Fig. 4 shows a summarized algorithm of the methodology for designing grapple buckets.

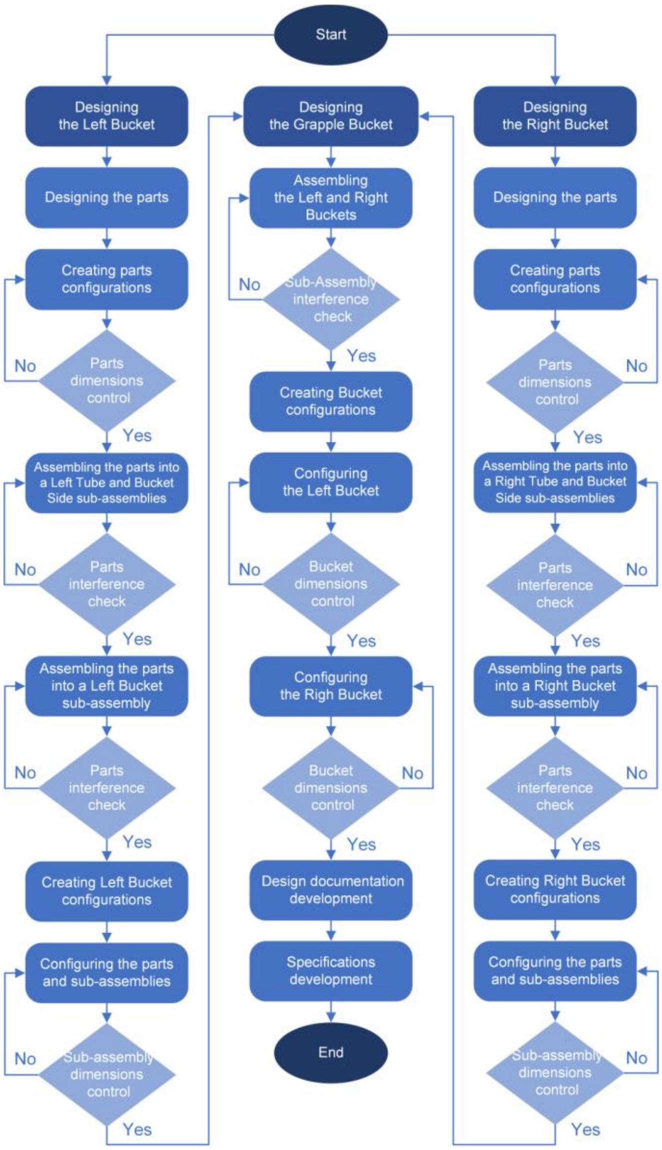


Fig. 4. *Grapple buckets design algorithm.*

A single 3D model of the 600 mm (623016201) length grapple bucket has been developed firstly. After that, the 800 mm (623016204) and 1000 mm (623016207) length grapple buckets has been modeled through configurations.

Each grapple bucket consists of two main sub-assemblies – Left Bucket and Right Bucket. The paper presents an example with Left Bucket, 1000 mm. The same approach is used to design the Right Bucket.

3.2. Parametric modeling of Left Tube and Right Tube.

An example with a Left Tube, 1000 mm sub-assemblies is considered. The 3D model of the Left Tube is parametrically modeled through configurations and Fig. 5 shows its components.

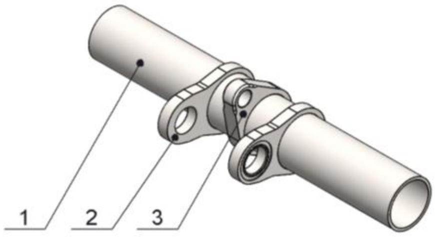


Fig. 5. *Components of the Left Tube, 1000 mm.*
1 – Tube, 2 – Lateral Ear, 3 – Central Left Ear

Part with position 1 is parametrically modeled and has configurations of different lengths.

To model parametrically the 3D model of the Left Tube, configurations are created in the *Configuration Manager* (Fig. 6). Each configuration represents a different length of the tube. For the corresponding bucket lengths, the Left Tube has the following configurations – 640 mm (623016201-LH-01), 800 mm (623016204-LH-01) and 1000 mm (623016207-LH-01).

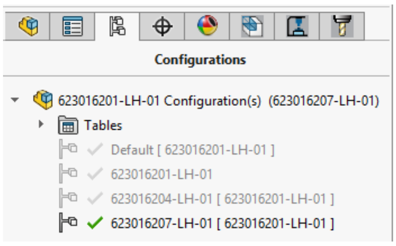
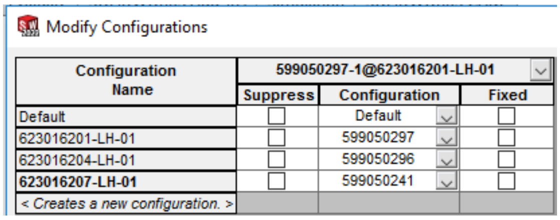


Fig. 6. *Configurations in the 3D model of the Left Tube.*

The next step is to configure the parts in the assembly of the tube. Part with positions 1 (Tube) contains configurations with different lengths. For each configuration of the Left Tube, the corresponding configuration of the part is set.

Fig. 7 shows the configurations of the Left Tube and the specified configurations of the Tube part. For the corresponding lengths of the Left Tube sub-assembly, the Tube part has the following configurations – 640 mm (599050297), 800 mm (599050296) and 1000 mm (599050241).


Modify Configurations

Configuration Name	599050297-1@623016201-LH-01		
	Suppress	Configuration	Fixed
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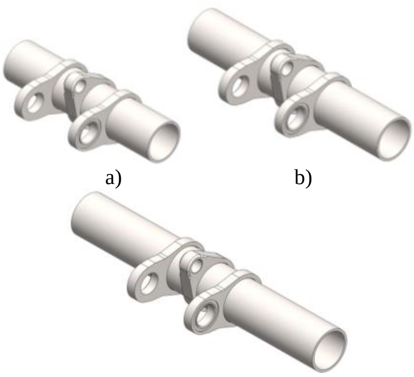
623016201-LH-01	☐	599050297	☐
623016204-LH-01	☐	599050296	☐
623016207-LH-01	☐	599050241	☐
< Creates a new configuration. >			

Fig. 7*. Configuring the Tube part.*

The configurations of the Tube part have different drawing numbers. The parts differ only in length, so one drawing of the part must be created with a parametric table including each of the variants.

Fig. 8 shows different lengths of the Left Tube, parametrically modeled with configurations.



a) b)

c)

Fig. 8. *Parametric models of the Left Tube.*
a) 640 mm, b) 800 mm, c) 1000 mm

The same approach is used to design the Right Tube sub-assembly. The 3D model of Right Tube is also parametrically modeled with configurations.

3.3. Parametric modeling of Left Bucket and Right Bucket.

An example with a Left Bucket, 1000 mm is considered. The 3D model of the Left Bucket is parametrically modeled through configurations and Fig. 9 shows its components.

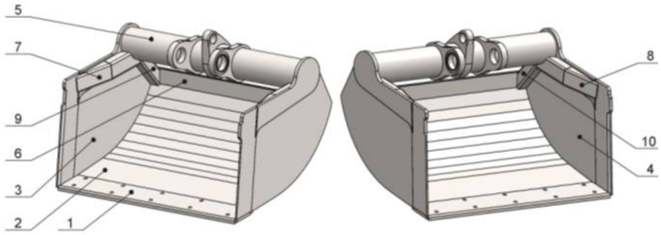


Fig. 9. *Components of the Left Bucket, 1000 mm.*
1 – Blade I, 2 – Bottom, 3 – Bucket Side I, 4 – Bucket Side II,
5 – Left Tube, 6 – Horizontal Rib,
7 – Rib I, 8 – Rib II, 9 – Rib III, 10 – Rib IV

Parts with positions 1, 2 and 6 are parametrically modeled and they have different length configurations. The Left Tube sub-assembly, position 5, is also parametrically modeled and has configurations with different lengths.

To model parametrically the 3D model of the Left Bucket, configurations are created in the *Configuration Manager* (Fig. 10). Each configuration represents a different length of the bucket. Buckets differ in length – 640 mm (623016201-LH), 800 mm (623016204-LH) and 1000 mm (623016207-LH).

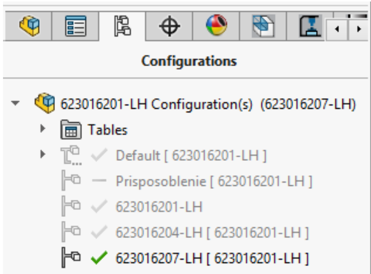
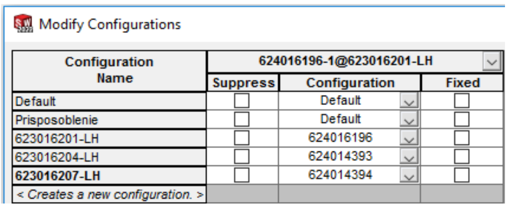


Fig. 10. *Configurations in the 3D model of the Left Bucket.*

The next step is to configure the parts in the assembly of the bucket. Parts with positions 1 (Blade I), 2 (Bottom) and 6 (Horizontal Rib) contain configurations with different lengths. For each configuration of the bucket, the corresponding configuration of the parts is set.

Fig. 11 shows the configurations of the Left Bucket and the specified configurations of the Blade I part. For the respective lengths of the bucket, the Blade I part has the following configurations – 640 mm (624016196), 800 mm (624014393) and 1000 mm (624014394).


Modify Configurations

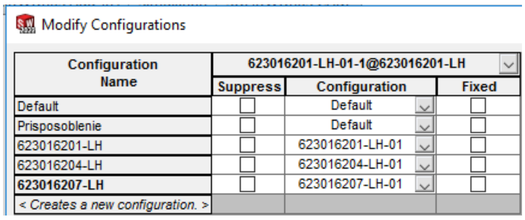
Configuration Name	624016196-1@623016201-LH		
	Suppress	Configuration	Fixed
Default	☐	Default	☐
Prisposoblenie	☐	Default	☐
623016201-LH	☐	624016196	☐
623016204-LH	☐	624014393	☐
623016207-LH	☐	624014394	☐
< Creates a new configuration. >			

Fig. 11. *Configuring the Blade I part.*

The configurations of the Blade I part have a different drawing number. The parts differ in construction – they have different lengths and different number and position of the holes. This requires the creation of a separate drawing for each of the variants.

The sub-assemblies in the assembly of the bucket should be configured. This is the Left Tube sub-assembly, it also has configurations with different lengths.

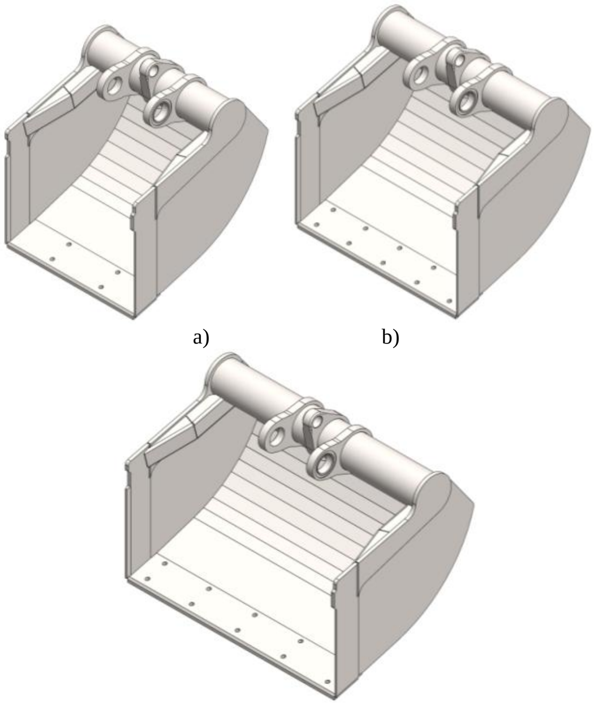
Fig. 12 shows the configurations of the Left Bucket and the specified configurations of the Left Tube. For the respective lengths of the Left Bucket, the Left Tube sub-assembly has the following configurations – 640 mm (623016201-LH-01), 800 mm (623016204-LH-01) and 1000 mm (623016207-LH-01).


Modify Configurations

Configuration Name	623016201-LH-01-1@623016201-LH		
	Suppress	Configuration	Fixed
Default	☐	Default	☐
Prisposoblenie	☐	Default	☐
623016201-LH	☐	623016201-LH-01	☐
623016204-LH	☐	623016204-LH-01	☐
623016207-LH	☐	623016207-LH-01	☐
< Creates a new configuration. >			

Fig. 12. *Configuring the Left Tube sub-assembly.*

Fig. 13 shows different lengths of the Left Bucket, parametrically modeled with configurations.


a) b)

c)

Fig. 13. *Parametric models of the Left Bucket.*
a) 640 mm, b) 800 mm, c) 1000 mm

The same approach is used to design the Right Bucket. The 3D model of Right Bucket is also parametrically modeled with configurations.

3.4. Parametric modeling of the Grapple Bucket.

The 3D model of the Grapple Bucket is parametrically modeled and has configurations with different lengths. The bucket model is an assembly consisting of a Left Bucket and a Right Bucket, assembled through the main planes *Front Plane*, *Top Plane* and *Right Plane* (Fig. 14).

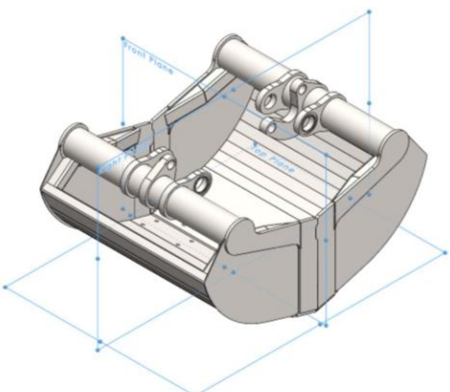
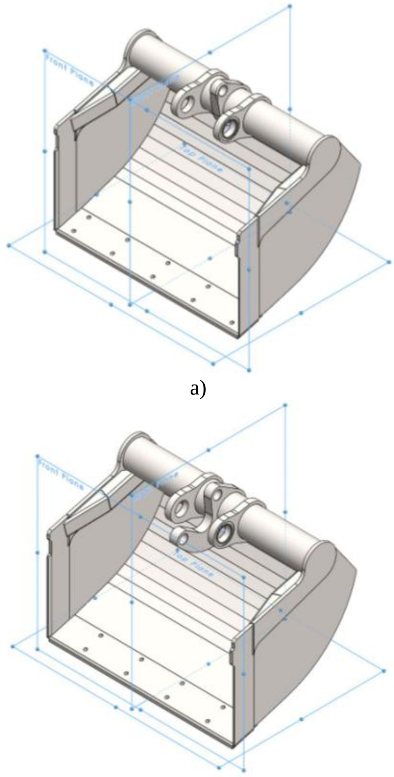


Fig. 14. *Assembling the main components of the bucket.*

To perform assembling, the 3D models of the sub-assemblies have in the same place coordinate systems and planes, that match with the coordinate system *Origin* and the main planes *Front Plane*, *Top Plane* and *Right Plane* in the 3D model of the bucket (Fig. 15).


a)

b)

Fig. 15. *Main planes in 3D models.*
a) Left Bucket, б) Right Bucket

To model parametrically the 3D model of the Grapple Bucket, configurations are created in the *Configuration Manager* (Fig. 16). Each configuration represents a different length of the bucket. Buckets differ in length – 640 mm (623016201), 800 mm (623016204) and 1000 mm (623016207).

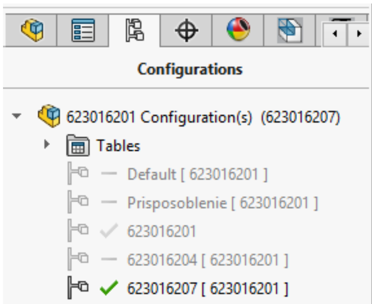
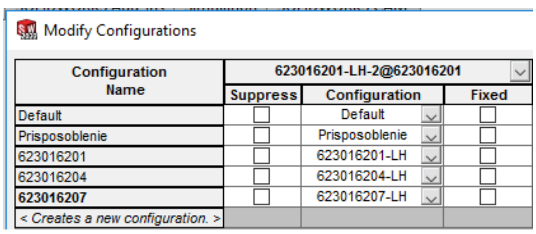


Fig. 16. *Configurations in the 3D model of the Grapple Bucket.*

The next step is to configure the sub-assemblies in the assembly of the bucket. The Left Bucket and the Right Bucket also contain configurations. For each bucket configuration, the corresponding configuration from the specific sub-assemblies is set.

The following figure shows the configurations of the Grapple Bucket and configurations which are set for the Left Bucket.

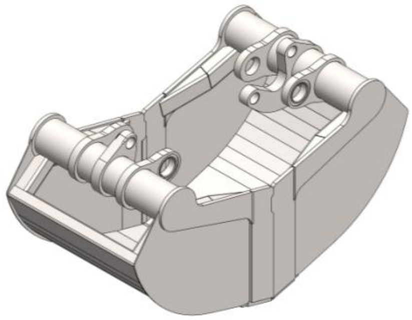

Modify Configurations

Configuration Name	623016201-LH-2@623016201		
	Suppress	Configuration	Fixed
Default	☐	Default	☐
Prisposoblenie	☐	Prisposoblenie	☐
623016201	☐	623016201-LH	☐
623016204	☐	623016204-LH	☐
623016207	☐	623016207-LH	☐
< Creates a new configuration. >			

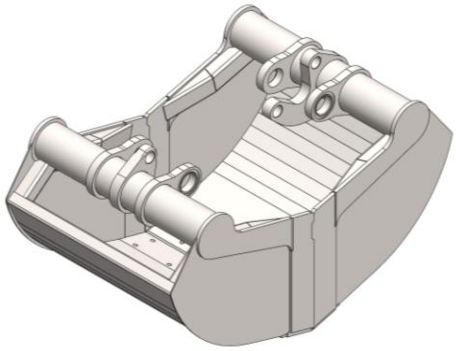
Fig. 17. *Configuring the Left Bucket.*

Configuring the Right Bucket is implemented using the same approach.

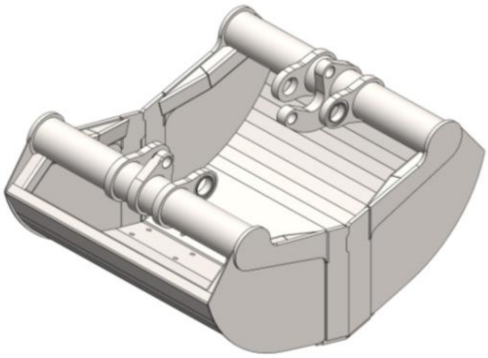
Fig. 18 shows different grapple bucket lengths, parametrically modeled with configurations.



a)



b)



c)

Fig. 18. *Parametric models of the Grapple Bucket.*
a) 640 mm, b) 800 mm, b) 1000 mm

3.5. Design documentation of the Grapple Buckets.

Complete design documentation has been made for the developed grapple buckets. The process of its creation is automated by using document *Template files* in the SolidWorks CAD system.

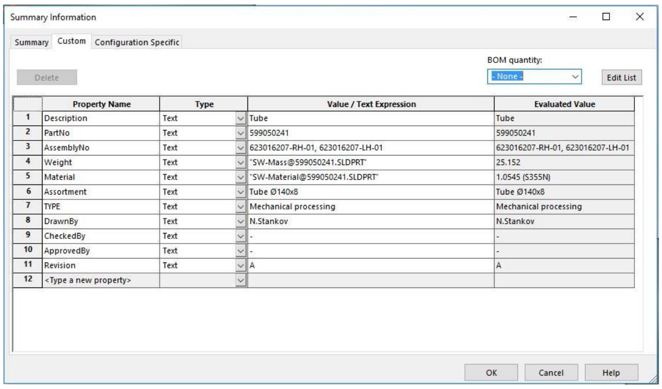
Template files for the *Part* and *Assembly* documents are used to create the 3D models of the parts and assemblies. In the template of each 3D model of the part or assembly, from the *File Properties* menu, in the *Summary Information* window, in the *Custom* section the required attributes (users and systems ones) are selected. The attributes for each configuration are filled in the *Configuration Specific* window [5, 6].

After the attributes of the 3D models having been filled in, the design documentation of the product (drawings and specifications) is developed. For the considered example of a grapple bucket, drawings of all parts, sub-assemblies (Left Tube, Right Tube, Left Bucket and Right Bucket) and the assembly of the Grapple Bucket are developed.

To develop the drawings, template files for *Drawing* documents are used, which represent the standard drawing formats – A4, A3, A2, A1 and A0. Information from the attributes is automatically visualized in the drawing tables, in the assembly drawing specifications and in individual product specifications [5, 6].

The following figures show examples of completed templates for the Tube part (599050241) and the Left Tube sub-assembly (623016207-LH-01).

The following attributes are used in the template of each *Part* – Description (Name of the Part), PartNo (Drawing number), AssemblyNo (Assembly from which the Part is), Weight (Weight of the Part – command "SW-Mass@Part1.SLDPRT"), Material (Material designation – command "SW-Material@Part1.SLDPRT"), Assortment (Type and dimensions of the workpiece), TYPE (Manufacturing operations), DrawnBy (Developed the document), CheckedBy (Checked the document), ApprovedBy (Approved the document), Revision (Document revision).



Summary Information

Summary | Custom | Configuration Specific

BOM quantity: - None -

Delete | Edit List

	Property Name	Type	Value / Text Expression	Evaluated Value
1	Description	Text	Tube	Tube
2	PartNo	Text	599050241	599050241
3	AssemblyNo	Text	623016207-RH-01, 623016207-LH-01	623016207-RH-01, 623016207-LH-01
4	Weight	Text	"SW-Mass@599050241.SLDPRT"	25.152
5	Material	Text	"SW-Material@599050241.SLDPRT"	1.0545 (S355N)
6	Assortment	Text	Tube Ø140x8	Tube Ø140x8
7	TYPE	Text	Mechanical processing	Mechanical processing
8	DrawnBy	Text	N.Stankov	N.Stankov
9	CheckedBy	Text	-	-
10	ApprovedBy	Text	-	-
11	Revision	Text	A	A
12	<Type a new property>			

OK | Cancel | Help

Fig. 19*. Template of the Tube part.*

The following figure shows the drawing of a Tube part, with an automatically filled table, based on the attributes specified in the 3D model of the part.

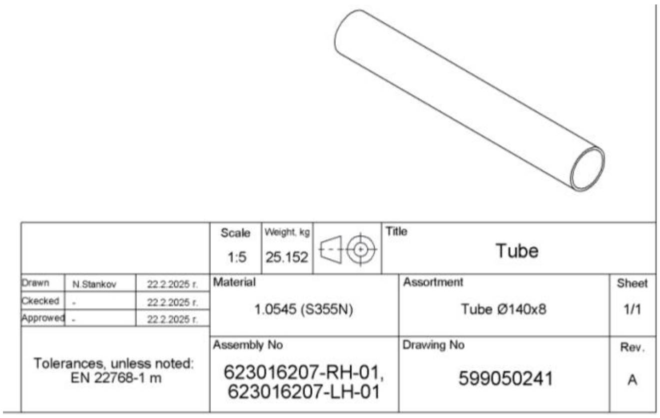
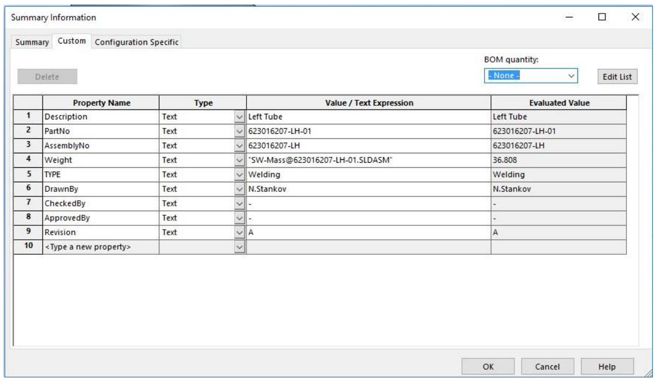


Fig. 20. *Drawing of the Tube part.*

The following attributes are used in the template of each *Assembly* – Description (Name of the Assembly), PartNo (Drawing number), AssemblyNo (Assembly of which the current Assembly is), Weight (Weight of the Assembly – command "SW-Mass@Assem1.SLDPRT"), TYPE (Manufacturing operations), DrawnBy (Developed the document), CheckedBy (Checked the document), ApprovedBy (Approved the document), Revision (Document revision).



Summary Information

Summary | Custom | Configuration Specific

BOM quantity: - None -

Delete | Edit List

	Property Name	Type	Value / Text Expression	Evaluated Value
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2	PartNo	Text	623016207-LH-01	623016207-LH-01
3	AssemblyNo	Text	623016207-LH	623016207-LH
4	Weight	Text	"SW-Mass@623016207-LH-01.SLDASM"	36.808
5	TYPE	Text	Welding	Welding
6	DrawnBy	Text	N.Stankov	N.Stankov
7	CheckedBy	Text	-	-
8	ApprovedBy	Text	-	-
9	Revision	Text	A	A
10	<Type a new property>			

OK | Cancel | Help

Fig. 21. *Template of the Left Tube sub-assembly.*

The following figure shows the drawing of the Left Tube sub-assembly, with an automatically filled table and specification, based on the attributes set in the 3D model of the assembly.

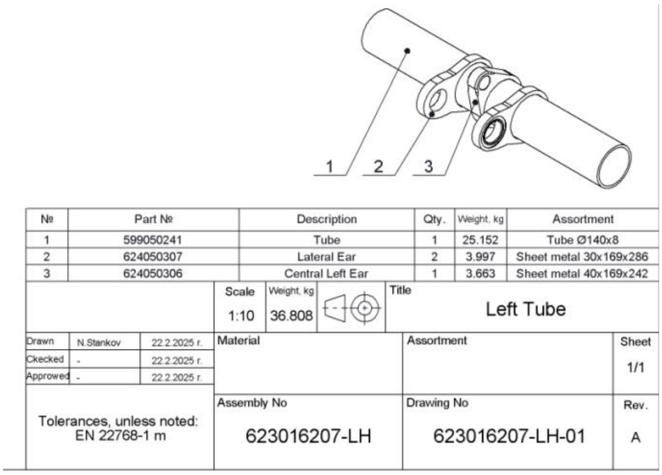

Fig. 22. Drawing of the Left Tube sub-assembly.

After the 3D models of the parts, sub-assemblies, assemblies and all drawings of the buckets have been developed, the next step is their management by the specialized systems – PDM and ERP. The design documentation is managed by the PDM system Solid-Works Enterprise PDM [3]. The various departments of the company have access to this information and operate with it through the ERP system Microsoft Dynamics NAV ERP [4].

Fig. 23 shows an example card of Grapple Bucket 1000 mm (623016207) in the ERP system.

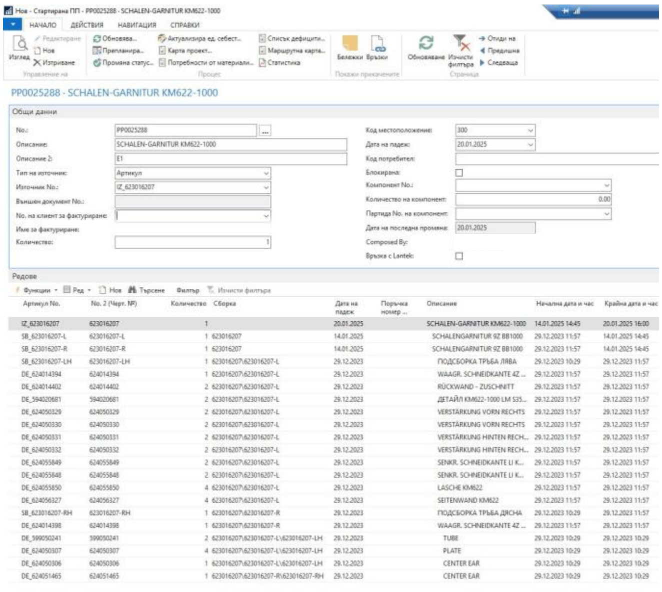

Fig. 23. *Card of the Grapple Bucket 1000 mm.*

4. Methods for modeling Grapple Buckets.

A certain product can be designed by applying two main methods – *traditional modeling* or *parametric modeling*. Both approaches are applied in practice. Depending on the products being developed, the method to be used is also chosen.

The paper discusses the approach for parametric modeling through configurations. Grapple buckets are being modeled. The modeling of 3D models of parts and assemblies as well as the creation of drawings and product specifications, are presented.

The parametric modeling approach through configurations has been chosen because of the advantages it has. The reason for using this approach becomes clear after comparing the two modeling methods.

4.1. Traditional modeling of Grapple Buckets.

In the traditional modeling approach, a 3D model is created for each bucket size. The 3D model of the bucket is an assembly composed of parts and sub-assemblies. All parts are modeled in advance. Parts that are structurally the same but differ in length, for different bucket models must be modeled as separate parts. There are 5 such parts in the grapple buckets. These parts are Tube, Blade I, Blade II, Bottom and Horizontal Rib (Fig. 5 and Fig. 9). Some of the parts are the same for all buckets and they are modeled once. After modeling the parts, they are assembled into the 3D model of the buckets. Table 1 shows the grapple buckets and their components.

Table. 1. *Grapple buckets, designed using the traditional modeling approach.*

Bucket size, mm	640	800	1000
Number of unique parts, that do not require changes	11		
Number of parts that require changes	5	5	5
Total number of parts	34	34	34
3D model of the bucket (Assembly)	Yes	Yes	Yes

This approach has many disadvantages:

- a large number of parts that must be modeled in advance;
- a large number of assemblies to model;
- possible modeling errors due to the large variety of 3D models of parts and assemblies;
- creation of a big amount of design documentation – drawings of parts, drawings of assemblies, specifications;
- redesigning the product when the size is different.

All these leads to a decreased efficiency of engineering work during design and an increased possibility of errors.

4.2. Parametric modeling of Grapple Buckets.

In parametric modeling through configurations, a single 3D model of the bucket is modeled and it includes all its variations (Table 2). The 3D model of the bucket is composed of parts and sub-assemblies. All parts are modeled in advance. Parts that differ only in length are modeled parametrically through configurations. The parts are assembled into sub-assemblies, which are modeled parametrically. The sub-assemblies are assembled into the assembly of the bucket, which is also modeled parametrically.

Table. 2*. Grapple buckets, designed using the parametric modeling approach.*

Bucket size, mm	640	800	1000
Number of unique parts, that do not require changes	11		
Number of parts that require changes	5		
Total number of parts	34		
3D model of the bucket (Assembly)	A single 3D model for all buckets		

Parametric modeling through configurations achieves high design efficiency, which is an advantage of the method. This is especially important when designing and modeling with CAD systems.

According to the data presented in the Table. 1 and Table. 2, the following conclusions can be made:

- in traditional modeling, the total number of parts and buckets that need to be modeled is bigger – **26** Parts and **3** Buckets, compared to **16** Parts and **1** Bucket in parametric modeling;
- parametric modeling significantly increases the efficiency of engineering work - the volume of design documentation created is reduced and the time required for modeling products is reduced;
- as a result of the smaller amount of design documentation, the number of errors in product modeling is significantly reduced;

- reducing design time is especially important in modern working conditions, where engineering departments consist of only a few people;

- parametric modeling is an approach that should be used for products with many variants and variations, as is the case with the considered grapple buckets.

5. Conclusion.

1. An approach for designing specialized products using a CAD system is presented. The implementation of parametric modeling through the SolidWorks CAD system allows significant automation in the design of grapple buckets. The use of configurations facilitates the creation of various product variants, reducing the time and volume of manually created documentation. Parametric modeling facilitates the process of developing products that have many variants and varieties.
2. The use of attributes (user and systems ones) in the 3D models of parts and assemblies enables the automated creation of design documentation (drawings of parts, drawings of assemblies and specifications).
3. The proposed approach of modeling through configurations improves the efficiency of engineering work, by reducing the design time, the volume of the designing documentation and errors during product design.
4. The presented integration between the 3D models and PDM system allows effective management of a large volume of design documentation. The files can also be used by other company departments through ERP system.
5. The presented approach is applicable to other similar products, which emphasizes its universal nature. In this way, similar problems related to the development and management of documents can be solved.

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