

CAD CONFIGURATOR FOR AUTOMATIC CONFIGURATION OF MODULAR STRONGROOMS

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Abstract: *Modular strongrooms (MSR) are complex and technical and technologically demanding products. They are designed at the individual request of the customer, who chooses the resistance grade of the room according to EN 1143-1 and defines dimensions of the available space to fit this product. The product architecture is modular and configuration is accomplished by a combination of standard modules whose number and dimensions must be adjusted in each new project. Manufacturers are required to be flexible in product design and to respond quickly to customer requirements. The MSR design process is a critical phase in product development, therefore its automation with advanced CAD systems is required. Within the CAD configurator for automatic MSR configuration, intelligent 3D templates of parts, modules and complete product as well as 2D templates of technical documentation are developed. The product is configured based on a platform that contains constraints, configuration rules, and interfaces for connecting modules. The CAD configurator is implemented in commercial software Autodesk Inventor. The proposed model has a high degree of flexibility and universality, can be further upgraded and can be integrated into the enterprise business system. Model verification is performed on a large number of practical MSR examples.*

Key Words: *CAD Configurator, Modular Strongrooms, Product Platform*

1. INTRODUCTION

The modern market requires manufacturers to be flexible in product design, to respond quickly to customer requirements (CRs) and to be able to develop products according to individual customer requirements. This led to the introduction of a Mass Customization (MC) strategy [1,2] based on the idea of producing highly variable products that meet individual customer requirements with production costs close to the mass production costs [3,4]. One of the main directions for supporting the mass customization paradigm is the development and application of product configuration systems (PCSs), also known as product configurators [5–7].

Product configurators are used in various industries and their application provides significant advantages [3,8–12]:

- the possibility of fulfilling a number of customer requirements,
- successful implementation of MC,
- shortening the time of product appearance on the market,
- reduction of costs,
- a greater variety of products is offered,
- shorter delivery cycles of the product variant,
- users are integrated into the design process, etc.

Configurable products usually use a modular architecture where the product is decomposed into functional modules whose selection and combination can be used to configure different product variants within the product family [13]. The development of configurable products is based on a product platform that represents a set of subsystems (components, modules or parts) and interfaces that form a common structure from which product variants can be efficiently developed and produced [14,15].

In this paper, the CAD configurator for automatic configuration of Modular Strongrooms (MSR) is presented. MSR is a complex and highly demanding engineering object that needs to meet a multitude of different and often conflicting requirements [16]. It is designed according to the individual requests of the customer who chooses the resistance grade of the room according to the standard EN 1143-1 and defines the available dimensions of the space in which it is necessary to place a product. The product architecture is modular and the configuration is achieved by a combination of standard modules whose number, dimensions and arrangement must be adjusted in each new project. Each MSR is essentially a new product because it has predefined dimensions in which to fit it and this requires repeating all phases of the design process [17]. Classical design methods take a lot of time and lead to frequent errors in construction documentation that are manifested in the process of making individual modules and especially in the process of assembling MSRs [17,18].

In the development of the CAD configurator of MSR, the platform for automatic configuration of MSR presented in the work of Grković et al. [17] is used. Within the platform a set of requirements and constraints, a set of modules, connections between modules, configuration rules and calculation of basic module parameters are defined.

A general model of the CAD configurator is given in Section 2. The design, principle of operation and verification of the MSR's CAD configurator are presented in Part 3. Part 4 is concluding considerations and giving directions for further research.

2. GENERAL MODEL OF CAD CONFIGURATOR

The process of product configuration is a set of activities in the selection of product elements from a predetermined set, in order to form a product variants that meets the set requirements while respecting known rules and restrictions between selected elements and modules [19-21].

A product configurator is a computer tool (program) based on expert systems (ES) or knowledge-based systems (KBS) that enables product customization by implementing a product configuration process [12, 22, 23].

The task of the CAD product configurator is to automatically transform customer requirements into a correct 3D product configuration model, as well as to generate all the necessary technical documentation. The focus of CAD product configurators is to use KBE (Knowledge Based Engineering) to transform a design problem into a configuration problem, using various dimensioning or calculation terms, design rules, or manufacturing constraints [24].

The realization of CAD configurators is possible in advanced commercial CAD software that has the ability to create, import, calculate and connect parameters and constraints as well as to implement configuration knowledge used to manage the characteristics of 3D models [25]. The implementation of configuration

knowledge enables automatic decision-making in the early stages of product development, which significantly affects the final characteristics and costs of the product [9].

Modern CAD systems, when designing parts and assemblies, rely on parametric design, which enables easier management of product geometry. In addition, they have add-ons that enable the implementation of engineering knowledge in the form of design rules, which leads to the possibility of designing automatic configurators with the help of intelligent templates. The intelligent template is a parametric, upgradeable and reusable block in a digital prototype that includes all the necessary rules, constraints, parameters and design features [25].

The development of CAD software has brought the possibility of integrating 3D models into PDF (known as 3D PDF), so that users can visually view the 3D model in three dimensions, without having to have CAD software but only Adobe Acrobat Reader.

The structure of the general model of CAD configurators is shown in Figure 1. It consists of: graphical user interface (GUI), product platform, intelligent templates, databases and reports in the form of technical documentation.

The user of the configurator (salesperson or customer) enters CRs via GUI. Based on that enters the basic parameters of the product configuration are automatically calculated in the product platform. The automated CAD configuration process of product takes place using intelligent templates, combining and adapting predefined 3D models of parts, modules and the entire product. As an input, intelligent templates use basic product configuration parameters, calculated within the product platform, and based on constraints, rules, connections and 3D models, it configures the product in detail with the required properties. All predefined parameters, constraints, connections, rules, and 3D models required to configure a modular product are stored in databases.

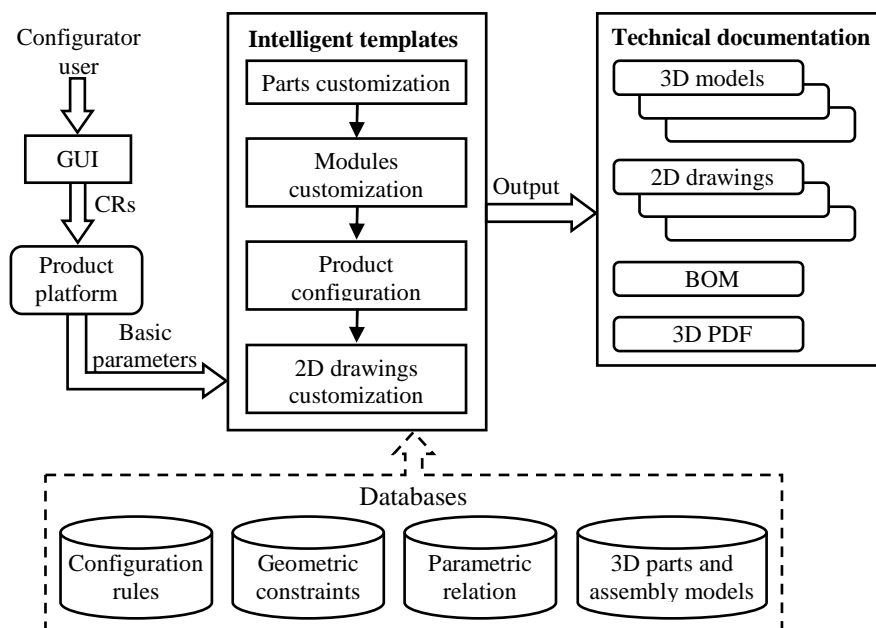


Fig. 1. CAD configurator structure

The output from the CAD configurator is technical documentation, as follows: detailed 3D models and 2D drawings of the product and all associated modules and parts, 3D PDF product assembly and BOM.

3. CAD CONFIGURATOR OF MSR

The implementation of the CAD configurator of MSR is performed by linking Autodesk Inventor Professional and MS Excel to ensure the import of parameters calculated within the product platform. In addition, the Inventor add-on iLogic enables the implementation of knowledge in the form of design rules used to manage various parameters (topologies, geometries, ...) and constraints.

3.1. Designing intelligent templates

The process of designing intelligent templates for the automatic CAD configurator MSR is performed in three steps:

- design of intelligent 3D parts template,
- design of intelligent 3D template of assemblies: modules and MSRs,
- design of 2D drawings template.

When designing intelligent templates, leading and driven parameters are defined in advance, as well as their exact mathematical or logical relations. The basic parameters of all MSR's modules and other data required to configure the MSR are calculated and recorded in tabular form (Excel file). By importing these parameters at the part, module and MSR level, leading parameters are obtained that are further related to other parameters within the 3D model. The parameters are directly linked so that any change in the value of the parameter in the source table (Excel table) results in an automatic change of parameters in the Inventor where all constraints and rules associated with these leading parameters are further updated.

a) Design of intelligent 3D part template

The design of the 3D model of the part is realized by linking the leading parameters with the elements of sketches and features, as well as by defining the design rules. The template designed in this way automatically adjusts the 3D model of the part using leading parameters.

An example of the required dimensional parameters to adjust a 2D sketch of one feature to form a part (shell profile of module A) is shown in Figure 2 where dimensions b_A and d are leading parameters and other dimensions are either fixed or driven (depend on leading parameters). In addition to the parameters, geometric constraints are defined in order to reduce the number of required dimensions as well as to achieve easier and faster adjustment process. In the mentioned example of the shell (Figure 3), geometric constraints of symmetry (lines delimiting shaded surfaces) as well as collinearity and equality (bold lines) were used.

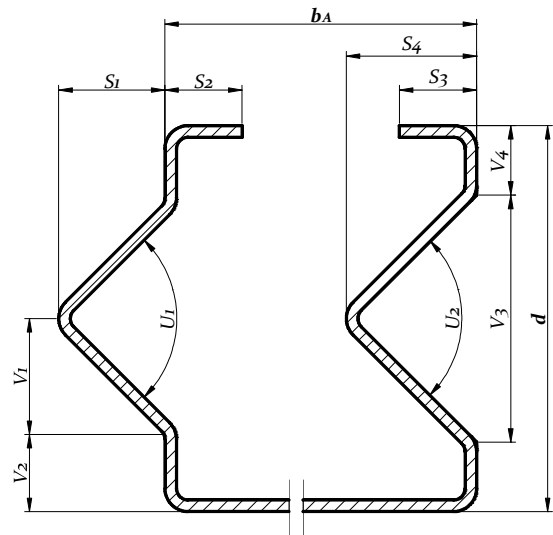


Fig. 2. Shell profile of module A with dimensional parameters

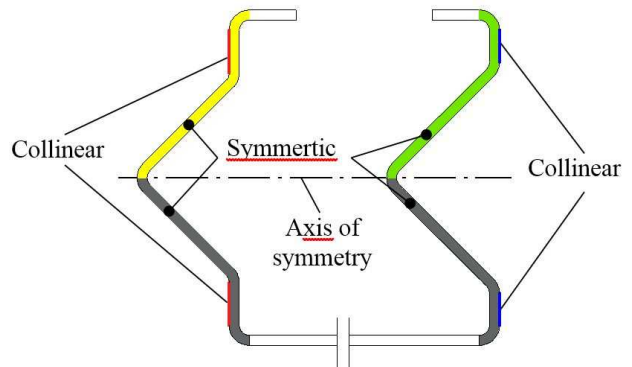


Fig. 3. An example of the geometric constraints in the 2D sketch

The length of the shell is determined by the leading parameter l_A , which completely defines its 3D model (Figure 4). A tabular representation of the association of several dimensional parameters with leading parameters, at the part level, is shown in Figure 5.

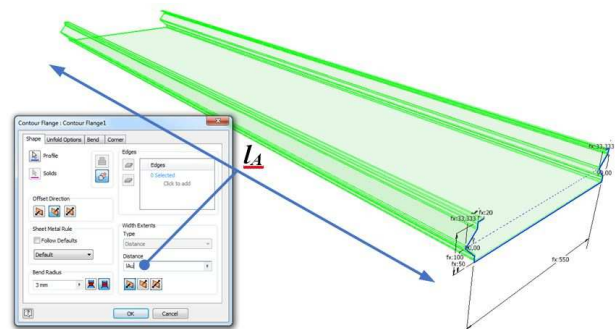


Fig. 4. Connection of shell length parameters

For a fully defined parametrically controllable 3D CAD part model, all the necessary operations are defined by means of which 3D geometric shapes are added or subtracted.

Parameter Name	Consumed by	Unit/	Equation	Nominal Value	Tol.	Model Value	Key	Exp	Comment
Model Parameters									
d1		mm	BendReliefWidth	3,048000	●	3,048000			
d2		mm	BendReliefDepth	1,524000	●	1,524000			
d3		mm	MinimumRemnant	6,096000	●	6,096000			
d4		mm	TransitionRadius	3,048000	●	3,048000			
IA		mm	IAu	2800	●	2800,000000			
d6	Contour Flange1	mm	3 mm	3,000000	●	3,000000			
d7	Contour Flange1	mm	0 mm	0,000000	●	0,000000			
d8		mm	Con	12,192000	●	12,192000			
d9		mm	Gap	3,048000	●	3,048000			
R		mm	JacobIRa	3,048000	●	3,048000			
bA	Sketch1	mm	bAu	550,000000	●	550,000000			
S2	Sketch1	mm	dAu / 5 ul	20,000000	●	20,000000			
S3	Sketch1	mm	dAu / 5 ul	20,000000	●	20,000000			
d	Sketch1	mm	dAu	100,000000	●	100,000000			
V3	Sketch1	mm	dAu / 2 ul	50,000000	●	50,000000			
U1	Sketch1	deg	90 deg	90,000000	●	90,000000			
U2	Sketch1	deg	90 deg	90,000000	●	90,000000			
S1	Sketch1	mm	dAu / 3 ul	33,333333	●	33,333333			
S4	Sketch1	mm	dAu / 3 ul	33,333333	●	33,333333			
Reference Parameters									
d0	Contour Flange1	mm	Thickness	3,048000	●	3,048000			
User Parameters									
IAu	IA	mm	2800 mm	2800,000000	●	2800,000000			
bAu	bA	mm	550 mm	550,000000	●	550,000000			
dAu	S4, S1, V3, d, ...	mm	100 mm	100,000000	●	100,000000			

Mathematical relations between parameters

Driven parameters

Leading (user) parameters

```

Edit Rule: Pravec podnih i plafonskih
Model File Tree Files Options Search and Replace Wizards
MODULPRIM-D.iam (Custom)
  Model Parameters
  User Parameters
  Excel Parameters
  Relationships
  Origin
  Lamela tipa B1:1
  Levo od vrata
  Lamela tipa A1:1
  Trezorska vrata:1
  Lamela tipa E:1
  Desno od vrata
Parameters Names
Parameter Equation
If Parameter("OPP") = 0 ul Then
  Constraint.IsActive("Flush:42") = True
  Constraint.IsActive("Flush:41") = True
  Constraint.IsActive("Flush:27") = False
  Constraint.IsActive("Flush:26") = False
Else
  Constraint.IsActive("Flush:42") = False
  Constraint.IsActive("Flush:41") = False
  Constraint.IsActive("Flush:27") = True
  Constraint.IsActive("Flush:26") = True
End If
  
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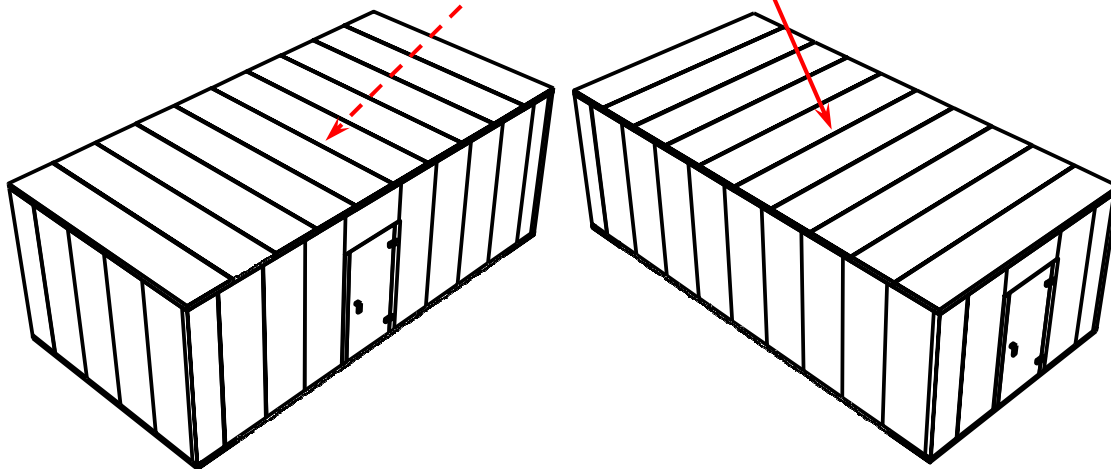


Fig. 6. Rule for orientation of floor and ceiling modules in iLogic environment

b) Design of intelligent 3D assembly templates

Intelligent module assembly templates are obtained by combining pre-designed part templates and positioning them using geometric constraints and multiplying them based on the required number of parts in the module.

The intelligent MSR assembly template contains all the predefined module templates as well as all the necessary knowledge, connections, and constraints to automatically configure the MSR. All modules are positioned based on geometric constraints and dimensional parameters. Logical design rules, which allow automatic management of parameters, constraints, connections and other characteristics of the 3D model, are written in the iLogic module. An example of a design rule that automatically makes a decision on the orientation of floor and ceiling modules is shown in Figure 6.

Module multiplication on MSR's sides is performed by directly linking the Pattern operation to the required leading parameters (number of modules and mutual distance). An example of the multiplication of module A, on the front wall right to the door, with previously imported user parameters (n_{AR} and b_A) is shown in Figure 7.

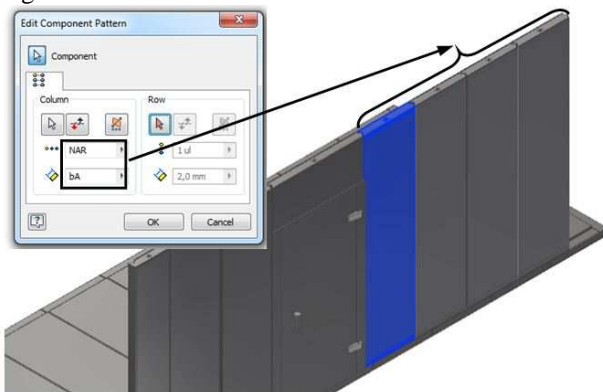


Fig. 7. Linking leading parameters when multiplying modules

Based on the product platform [17], it was observed that some of the modules sometimes participate and sometimes do not (when the number of modules = 0) in the configuration of MSR. For such modules, a design rule is defined which, based on the required number of modules per side, automatically includes/excludes the module from the assembly template of MSR. The complete code for this rule, for the whole assembly of MSR, is given in Figure 8.

Inventor, based on the rules, allows automatic export of MSR model in 3D PDF format, shown in Figure 9.

<pre> If Parameter("nAL") = 0 ul Then Component.IsActive("Pattern-left to the door ") = False Component.IsActive("Module A:4") = False NAL = 1 ul Else Component.IsActive("Pattern-left to the door") = True Component.IsActive("Module A:4") = True NAL = nAL End If If Parameter("nA1") = 0 ul Then Component.IsActive("Module A1:1") = False Else Component.IsActive("Module A1:1") = True End If If Parameter("nAR") = 0 ul Then Component.IsActive("Pattern-right to the door") = False Component.IsActive("Module A:5") = False NAR = 1 ul Else Component.IsActive("Pattern-right to the door") = True Component.IsActive("Module A:5") = True NAR = nAR End If If Parameter("nAS") = 0 ul Then Component.IsActive("Pattern-lateral side-r") = False Component.IsActive("Module A:1") = False Component.IsActive("Pattern-lateral side-l") = False Component.IsActive("Module A:3") = False NAS = 1 ul Else Component.IsActive("Pattern-lateral side-r") = True Component.IsActive("Module A:1") = True Component.IsActive("Pattern-lateral side-l") = True Component.IsActive("Module A:3") = True NAS = nABS End If If Parameter("nAB") = 0 ul Then Component.IsActive("Module A:2") = False Component.IsActive("Pattern-back side") = False NAB = 1 ul Else Component.IsActive("Module A:2") = True Component.IsActive("Pattern-back side") = True NAB = nAB End If If Parameter("nD") = 0 ul Then Component.IsActive("Pattern-ceiling") = False Component.IsActive("Module D:1") = False Component.IsActive("Pattern-floor") = False Component.IsActive("Module D:11") = False ND = 1 ul Else Component.IsActive("Pattern-ceiling") = True Component.IsActive("Module D:1") = True Component.IsActive("Pattern-floor") = True Component.IsActive("Module D:11") = True ND = nD End If </pre>	<p>Front side – modules left to the door</p> <hr/> <p>Front side- modules right to the door</p> <hr/> <p>Lateral side</p> <hr/> <p>Back side</p> <hr/> <p>Floor and ceiling</p>
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Fig. 8. iLogic program code for automatic switching on/off of the module from the assembly of MSR

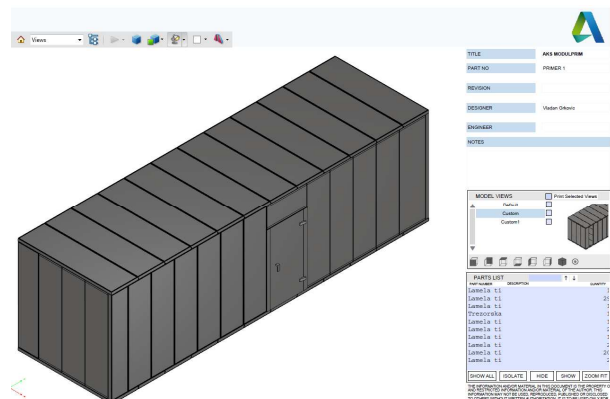


Fig. 9. 3D PDF assembly of MSR

c) Design of 2D drawing template

The development of 2D technical documentation is a long-term and uncreative work, so it is worth automating. Automated documentation is created using a 2D drawing template. CAD software automatically updates every change on the 3D model in the technical drawing.

For parts that are designed in the sheet metal design module, the bent and flat pattern of the part is automatically updated in the technical drawing. From the flat pattern, the shape and dimensions of the flat stock are obtained, as well as the lines and bending angles, which can be seen in the example of one part (the shell of module A) in Figure 10.

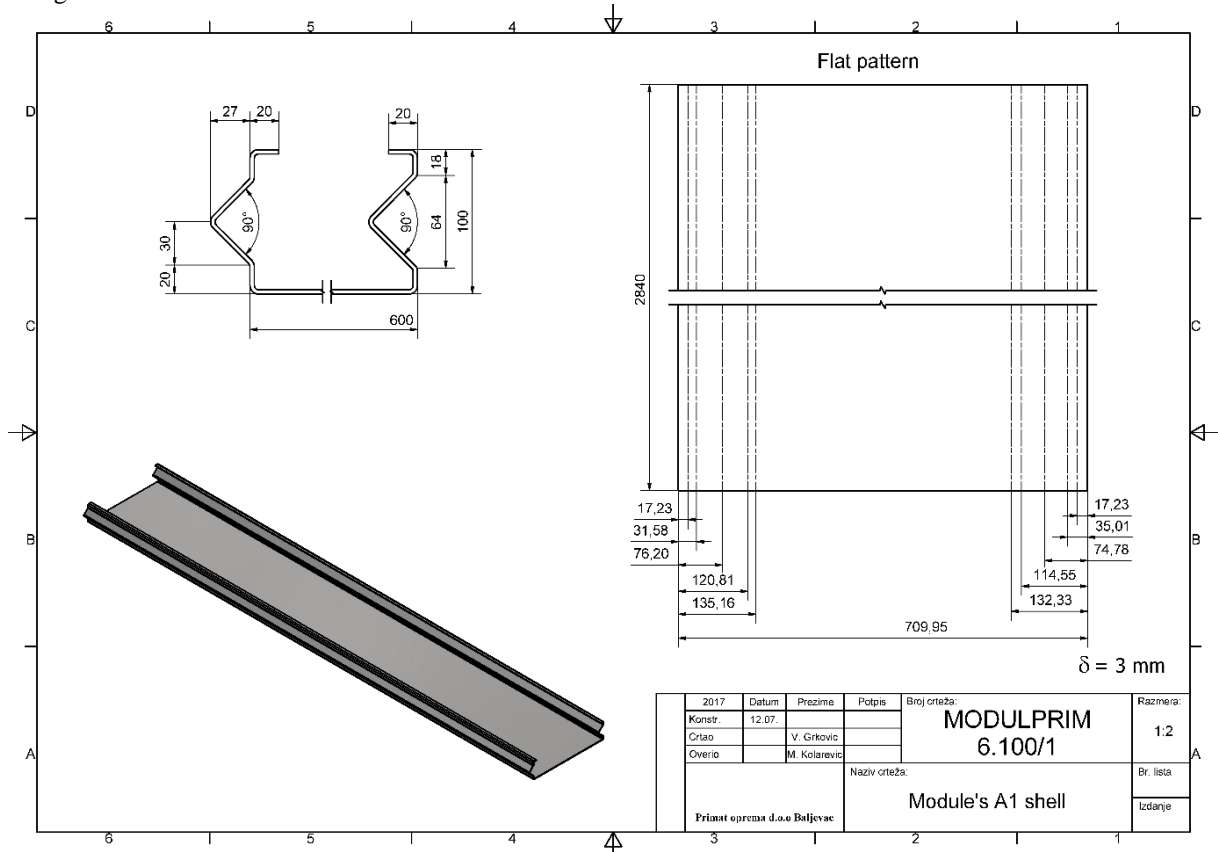


Fig. 10. Technical drawing of module A shell

3.2 MSR CAD Configurator operation algorithm

The process of using the MSR CAD configurator begins by entering CRs in the GUI, after which intelligent templates are started automatically. By running intelligent templates, the basic parameters are loaded, on the basis of which all necessary parts and modules are adjusted and the MSR assembly is configured. After that, 2D drawings are adjusted, 3D PDF is exported and all documents are saved.

The configuration of the MSR is performed according to the pseudo code shown in algorithm 1.

All activities in the CAD configurator are automated.

3.3 Model verification

The purpose of verification is to assess whether a product, service, or system meets the set of specifications defined by the design. When it comes to the verification of analytical methods or simulation models, the verification should check whether it contains all the necessary components and whether it works as intended, that is, to answer the question "is the model made correctly"? [26]. Accordingly, testing of the CAD configurator of MSR require verification that the product parameters, rules, and constraints defined by the product platform are properly implemented and that the CAD

configurator correctly modeled the product, modules, parts, and 2D design documentation.

For verification of the developed CAD configurator of MSR, 8 examples of MSR type MODULPRIM 5 were selected, which dimensions are shown in Table 1. These examples are practically realized in the previous period based on the rules defined by the product platform developed in Grković et al. [17].

Table 1. Basic dimensions of MSR MODULPRIM 5 for selected examples

CRs	Example							
	1	2	3	4	5	6	7	8
A [mm]=	9500	2050	3560	2200	2830	2350	4430	2900
B [mm]=	2800	3890	2150	3600	3590	3975	2150	8460
C [mm]=	2900	2910	2500	2500	2560	2540	2680	2800
D [mm]=	4650	400	1860	506	705	575	2793	400
E [mm]=	1200	1150	1200	1104	1200	1200	1137	1200
F [mm]=	2110	2110	2105	2110	2165	2155	2110	2150

The verification process included a comparison of the technical documentation obtained with the help of the CAD configurator of MSR and the construction documentation of realized MSRs. Verification confirmed the correctness of the developed CAD configurator of MSR.

Algorithm 1. Pseudo code of the MSR CAD configurator

```
1. input CRs in GUI
2. calculation basic parameters of product configuration according to product platform
3. save basic parameters of product configuration in excel table
4. open assembly MSR template
5. load basic MSR parameters from excel table
6. for i=1:s //for all MSR sides
7.   for j=1:p(i) //for all modules per MSR side(i)
8.     if module(Mij) is needed for this area then
9.       open module(Mij) template
10.      load excel data (basic module(Mij) parameters)
11.      for c=1:rij //for all parts in module(Mij)
12.        open part(Dijc) template
13.        load excel data (basic part(Dijc) parameters)
14.        dimensions calculation according relation and load data
15.        updateing all part(Dijc) features according to dimensions and constrains
16.        save and close
17.        update part(Dijc) drawing
18.      next c //next part
19.    end for
20.    updating all parts in module(Mij)
21.    parts arrangements (positioning) according to their constraints
22.    save and close module(Mij)
23.    update module(Mij) drawing
24.    update module(Mij) in MSR assembly
25.    arrangement module(Mij) in MSR assembly
26.    patterning (multiply) module(Mij) according to required number(nij)
27.  else if
28.    do not open and updating module(Mij)
29.    disable (delete, suppressed) module(Mij) in MSR assembly
30.  end if
31. next j //next module
32. end for
33. next i //next side
34. end for
35. save MSR template
36. update MSR drawing
37. export MSR BOM and 3D PDF
```

4. CONCLUSION AND FURTHER RESEARCH DIRECTIONS

CAD configurator of MSR was developed as part of the model of integrated automatic configuration system of complex products developed at the Faculty of Mechanical and Civil Engineering in Kraljevo. The model consists of 9 modules that are integrated into one unit on the basis of which it is possible to obtain the optimal configuration variant of the product that meets the individual requirements of the customer and which is the most economic for the manufacturer.

By applying the proposed CAD configurator, it is possible to offer the customer the desired product configuration while reducing operating costs in the process of contracting through the automation of the process of product configuration and preparation of technical documentation. On the other hand, work efficiency has been increased by reducing or eliminating repetitive tasks and shortening the engineering time required to work on product design and redirecting it to other creative jobs.

The results achieved using CAD configurators confirm that modern automated configuration systems are key to the successful implementation of the Mass Customization strategy and that it is possible to produce highly variable products that meet a wide range of customer requirements, with the product price close to the mass production.

The proposed CAD configurator has a high degree of flexibility and universality, can be further upgraded and can be integrated into the company's business system. Therefore, further work on its improvement will be focused on:

- improvements and enhancements of algorithmic structures,
- formation of a single CAD configurator for the whole MSR family,
- model expansion with special modules with additional functions (ventilation and cable routing),
- full integration of CAD / CAPP / CAM system,
- integration of the model into the business system of the company,
- continuous verification and validation of the model and
- development of a collaborative work environment.

In addition, future research in this area should explore new possibilities and limits of application of the presented concept through the specific application of developed CAD configurator to a wider range of products and intensive cooperation with industrial partners in the environment.

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