DR.SC.-01 REQUEST FOR APPROVAL OF THE DISSERTATION TOPIC[1]

GENERAL INFORMATION AND PERSONAL CONTACT INFORMATION OF THE DOCTORAL CANDIDATE

First and last name, and title of the doctoral candidate:	Mladen Burić, mag. ing. mech.		
Provider of the study programme:	University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture		
Name of the study programme:	Mechanical Engineering and Naval Architecture		
Scientist ID of the doctoral candidate:	35002987		
Approval of topic for acquiring a PhD *(please fill in appropriate box)*:	☒ within programme-based doctoral study	☐ on the basis of scientific achievement	☐ Dual doctorate (Cotutelle de these)
First and last name of mother and/or father:	Ivka i Ilija Burić		
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CURRICULUM VITAE OF THE DOCTORAL CANDIDATE

Education *(in chronological order, with most recent first)*:	1. University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Graduate study, Croatia (2011./2012.) 2. University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Undergraduate study, Croatia (2010./2011.)
Work experience *(in chronological order, with most recent first)*:	07.01.2019. - now: Mechanical Design Engineer, PIA Automation, Zagreb, Croatia 17.10.2016. - 03.01.2019.: Design Engineer, Yazaki Europe Limited, Zagreb, Croatia 07.01.2013. - 14.10.2016.: Mechanical Integrity Engineer, Alstom & General Electric, Karlovac, Croatia 01.09.2011. - 29.02.2012.: student practice, ABB Turbocharging, Baden, Switzerland
Bibliography and active participation in conferences:	1.Buric, Mladen; Brcic, Mario; Skec, Stanko, Towards Automated Drafting in CAD Systems. // 4th International Conference on Electronics and Electrical Engineering Technology (EEET 2021), Nanjing: ACM, 2021. str. 233-238 doi:10.1145/3508297.3508335 (predavanje, međunarodna recenzija, cjeloviti rad (in extenso), znanstveni) 2.Burić, Mladen; Marjanović, Dorian, A TOOL FOR IDEALISATION OF CAD MODELS. // DS92: Proceedings of the DESIGN 2018, 15th International Design Conference Dubrovnik: Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb, Croatia; The Design

[1] Please name file as: DR.SC.-01 – Last name and first name of Doctoral Candidate.doc
Please send the filled -out form DR.SC.-01, in electronic and written format, and signed, to the appropriate Registrar's Office.

	Society, Glasgow, UK, 2018. str. 205-214 doi:10.21278/idc.2018.0367 (predavanje, međunarodna recenzija, cjeloviti rad (in extenso), znanstveni) 3.Buric, Mladen; Katana, Branko, Low-Cost Experimental Setup for 2D Digital Image Correlation Method. // 5TH INTERNATIONAL CONFERENCE "VALLIS AUREA", Požega, 2016. str. 43-53 (predavanje, međunarodna recenzija, cjeloviti rad (in extenso), znanstveni) 4.Katana, Branko; Buric, Mladen, Polymer Materials in the Food Industry. // 5TH INTERNATIONAL CONFERENCE "VALLIS AUREA", Požega, 2016. str. 199-206 (predavanje, međunarodna recenzija, cjeloviti rad (in extenso), znanstveni)

TITLE OF THE PROPOSED TOPIC

Croatian:	Metoda za računalno potpomognutu detekciju simetrije u 3D CAD modelima
English:	A method for computer-aided symmetry detection in 3D CAD models
Title in the language of the dissertation (if it is not Croatian or English)	-
Area/field/branch (if the doctoral study is performed in a branch)**:**	Technical sciences / Mechanical engineering / General mechanical engineering (constructions)

PROPOSED OR POTENTIAL MENTOR(S)

(name the second mentor in case of interdisciplinary research or if there is another reason for more than one mentor)

	First name and last name, and title:	Institution, country:	E-mail:
First mentor:	**Assist. Prof. dr. sc. Stanko Škec**	**University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia**	**stanko.skec@fsb.hr**
Second mentor:			

MENTOR'S COMPETENCES – list of up to five relevant works published in the last five years

First mentor:	1. Horvat N, Martinec T, Lukačević F, Perišić MM, Škec S. The potential of immersive virtual reality for representations in design education, Virtual reality, 2022. 2. Horvat N, Martinec T, Becattini N, Skec S. Identifying Indicators for the Use of Virtual Prototypes in Distributed Design Activities, Computer-Aided Design and Applications, 2022. 3. Lukačević F, Škec S, Törling P, Štorga M. Identifying subassemblies and understanding their functions during a design review in immersive and non-immersive virtual environments, Frontiers of Engineering Management, 2020. 4. Kosec P, Škec S, Miler D. A comparison of the tolerance analysis methods in the open-loop assembly, Advances in production engineering & management, 2020. 5. Martinec T, Škec S, Perišić MM, Štorga M. Revisiting Problem-Solution Co-volution in the Context of Team Conceptual Design Activity, Applied Sciences-Basel, 2020.
Second mentor:	

TOPIC OUTLINE

Summary in Croatian *(no more than 1000 characters with spaces):*	Računalno potpomognuta detekcija simetrije bavi automatskom identifikacijom ravnina, osi ili točaka simetrije u 2D ili 3D digitalnim objektima. 3D digitalni objekti koji će biti predmet istraživanja u ovom radu jesu kruti CAD modeli s rubnim prikazom. Postojeći pristupi za računalno potpomognutu detekciju simetrije u 3D CAD modelima s rubnim prikazom ograničeni su na samo pet osnovnih analitičkih površina (ravnina, cilindar, stožac, sfera i torus), iako CAD modeli često sadrže i numeričke površine (npr. Bézier, B-Spline, itd.). Stoga je glavni cilj ove disertacije

	predložiti metodu i razviti računalno okruženje za detekciju egzaktne globalne i parcijalne refleksijske i osne simetrije u CAD modelima s rubnim prikazom koji sadrže analitičke i numeričke površine. Predložena metoda i računalno okruženja bit će podvrgnuti validaciji, s glavnim ciljem utvrđivanja točnosti detekcije simetrije, odnosno otkrivanja odgovarajućih ravnina i osi simetrije.
Summary in English *(no more than 1000 characters with spaces):*	Computer-Aided Symmetry Detection deals with the automatic identification of the planes, axes, or points of symmetry in 2D or 3D digital objects. The 3D digital objects that will be the subject of research in this paper are solid CAD models with Boundary representation (B-rep). The existing Computer-Aided Symmetry Detection approaches related to B-rep CAD models are restricted to only five basic analytic surfaces (plane, cylinder, cone, sphere, and torus), although CAD models often contain also numerical surfaces (e.g., Bézier. B-Spline, etc.). Hence, the main objective of the present thesis is to propose a method and develop a computational environment for the detection of exact global and partial reflectional and axisymmetry in B-rep CAD models that contain analytical as well as numerical surfaces. The proposed method and the computational environment will be subjected to validation where the main goal is to evaluate the symmetry detection correctness, i.e., identification of the corresponding planes and axes of symmetry.

Introduction and overview of research conducted hitherto *(suggested length: 7000 characters with spaces)*

Geometric symmetry (hereinafter referred to as symmetry) is often introduced into mechanical parts or assemblies as it is beneficial in terms of function [1], structural analysis [2], manufacturing [3], assembling [4], complexity reduction, or aesthetics. Symmetrically designed mechanical parts are less prone to assembly errors and require less assembly time [4]. Symmetry is useful in manufacturing to define the parting planes in the stamping and molding processes [3]. In Computer-Aided Engineering (CAE) symmetry is often exploited to reduce the size of the 3D model which consequently reduces the computational effort of the analysis [2]. In technical drawing, symmetrical parts may be drawn half in section and half in outside view [5], which may reduce the number of necessary views. In mechanics, the symmetry properties of a structure may have a distinct influence on the static and kinematic behavior of the structure [6]. Based on the mentioned examples, it can be concluded that symmetry is an important property that is often used in mechanical engineering.

During Computer-Aided Design (CAD), there is often the need to check if symmetrically designed 3D models indeed exhibit the desired type of symmetry. However, the symmetry information is seldom directly stored in the native CAD models and never in the neutral exchange file formats (e.g., STEP, IGS, etc.). An exceptional case when the symmetry information might be stored in the native CAD model is when the final geometric shape has been created by a mirroring operation with respect to a plane. Hence, the most common way to retrieve symmetry information is the visual recognition by the human. However, for very complex geometric shapes or a large number of 3D models from the CAD repository, visual recognition may be too difficult and time-consuming [3]. In addition, exact symmetry cannot be obtained by human visual recognition in any CAD model [7]. Another way to retrieve the symmetry information is by employing Computer-Aided Symmetry Detection (CASD), which deals with the automatic identification of the planes, axes, or points of symmetry in 2D or 3D digital objects. CASD has received considerable attention not only in mechanical engineering [2] but also in other fields such as mathematics [8], computer engineering [9], medicine [10], architecture and civil engineering [11], etc. In mechanical engineering, CASD has been exploited for retrieval [12], compression [13], and alignment [14] of 3D CAD models, CAE [2], Design for Assembly [15], detecting design intent in scanned models from Reverse Engineering [16], etc.

An object is symmetric if it is invariant under geometric transformations such as *reflection*, *rotation*, *translation*, or *combinations* of these [17]. CASD can be classified according to different criteria: the type of input data – *discrete* [9] vs *continuous* [8] and *2D* [18] vs *3D* [20], scale – *global* [3] vs *partial* (or quasi-symmetry) [15] vs *local* [17], accuracy – *exact* (perfect) [3] vs *approximate* (imperfect) [21], distance metrics – *extrinsic* [9] vs *intrinsic* [10], and the type of transformation – *reflectional* [7], *rotational* (*axisymmetry* [3] and *cyclic* [2] symmetry), *dihedral* [18] (combination of reflectional and rotational symmetry), etc. The present research will be focused on exact symmetry because the accuracy of the symmetry detection of mechanical parts needs to be at least within the accuracy of the manufacturing process (10^{-6} m) [3]. Further, the scope of the research is to detect reflection and axisymmetry, which are the two most common types of symmetry in mechanical parts [15]. Moreover, mechanical parts often exhibit global and partial symmetry so this research will address those two types of symmetries. Global symmetry means that the whole object is symmetric, while partial symmetry means that the global symmetry of the object is disturbed by local non-symmetric regions [15].

Generally, the CASD approaches related to 3D digital objects are divided into *geometry-based* and *view-based* [19]. The *geometry-based approaches* uses the geometrical information and the typical inputs are solid CAD models [3][7], cable-strut structures [20], voxel models [22], NURBS models [12], point clouds [23][24], mesh models [25], etc. In some cases, the initial input models may be further processed and converted, e.g., mesh models into voxel models [22] or point clouds [23]. The geometry-based approach addresses the detection of approximate [9] as well as exact symmetry [3]. In the *view-based approach*, the 3D object is converted into a 2D representation such as an image [21] or a projected view [19]. However, this approach deals with the detection of approximate symmetry. The common strategy of CASD is to first identify a large number of candidates for the plane of symmetry (POS) or the axis of symmetry (AOS) for the given input model. The candidates are then evaluated with respect to the input model with the aim to determine if some of them also represent the true POS/AOS. The POS/AOS candidates are obtained from the principal component analysis [26], pair matching [15], local surface properties [3], etc. Some of the proposed techniques [18][20] are constrained to only detect POS/AOS that pass through a reference point (e.g., origin, centroid, the center of mass, etc.), which is appropriate for detecting exact, but not for approximate and partial symmetries.

The symmetry detection in solid CAD models has been studied from two aspects: *feature* and *Boundary representation* (B-rep). The first aspect uses design features, Boolean operations, and the feature (history) tree for the detection of exact reflectional and axisymmetry in parts [7] and assemblies [27]. However, this aspect is restricted to native CAD models and may be sensitive to the designer's bad modeling habits (e.g., redundant feature modeling, modeling of symmetric shapes using non-symmetric features, etc.). The second aspect uses geometrical and topological information of the B-rep [3][15]-[17] as input, which enables using native CAD models as well as neutral exchange file formats. To identify global reflectional and axisymmetry in B-rep CAD models, the study [15] proposed a loop-based approach (a loop is a closed circuit of edges bounding a face). The approach used loop properties (e.g., loop area, centroid, normal, etc.) and a pairing algorithm to identify identical loop pairs. The candidates for the POS and AOS were calculated as the resultant vector of two unit normal vectors from identical loop pairs. Then the candidates were ranked according to cumulative loop area and compared to extract the final POS and AOS. Another research study [16] proposed a divide-and-conquer approach for detecting exact and partial global reflectional and axisymmetry in B-rep CAD models, using faces as input. First, in the divide phase, the candidates for the POS/AOS were obtained through the local symmetry properties of the faces and their intersections. Then, in the conquer phase the local symmetry properties were propagated to the global level, by matching coincident local POS/AOS candidates into global POS/AOS. The study in [16] proposed an approach for detecting cyclic regions in quasi-axisymmetric B-rep CAD models using manually assigned AOS as input. Further, in [17] a graph-based approach was used to extract multi-scale (i.e., at different geometric scales) symmetric regions and extract symmetry relations among these regions. The proposed approach addressed exact reflectional, rotational, and translational symmetry.

Generally, the proposed CASD approaches related to B-rep CAD models have several drawbacks: (1) they are restricted to only five basic analytic surfaces (plane, cylinder, cone, sphere, and torus), although solid CAD models often contain also numerical surfaces, (2) partial symmetry is propagated from the local to the global level and so far no adequate characterization of partial symmetry has been proposed, and (3) they are computationally complex due to a large number of POS/AOS candidates and therefore limited for practical application.

Objective and hypotheses of research[2] *(suggested length: 700 characters with spaces)*

Until now, the CASD approaches related to B-Rep CAD models have dealt only with analytical surfaces, although many CAD models are compounded of analytical and numerical surfaces [28]. Hence, the main objective of the present research is to propose a method and develop a computational environment for the detection of exact global and partial reflectional and axisymmetry in B-rep CAD models that contain analytical and numerical surfaces. The research will be limited to solid CAD models with manifold geometry and to single parts with one body.

The main hypothesis of the research:

A geometry-based method can be used to detect exact global and partial reflectional symmetry and axisymmetry in B-rep CAD models that contain analytical and numerical surfaces.

Material, participants, methodology and plan of research *(suggested length: 6500 characters with spaces)*

Based on the introduction and overview of the existing research, it is evident that further research is needed when it comes to symmetry detection in solid CAD models with B-Rep where the surfaces are of two types: analytical and numerical. Within the analytical surfaces, the shape information is explicit, while within numeric surfaces the shape is controlled by the position of a set of control points (additionally, there can be weights and knots in more advanced forms) [28]. Numerical surfaces may be created automatically by the CAD system in the background or intentionally by the user. For instance, when fillet or chamfer features are used to round off or break edges, the CAD system may automatically create numerical surfaces. On the other hand, in certain cases, the user needs to use numerical surfaces (e.g., Bézier, B-Spline, etc.) to model complex shapes (e.g., an airplane's fuselage or wing, car body, turbine blade, etc.). Hence, to overcome the limitation of the past research where only analytical surfaces were included in the symmetry detection, the present research will address both analytical and numerical surfaces.

The research methodology is based on [29] and will consist of three phases: (1) preliminary research, (2) proposal of the method and development of the computational environment for symmetry detection in CAD models with B-Rep, and (3) validation of the method and computational environment.

1. The preliminary research will start with an overview of existing scientific and expert literature within the research area to give an initial description of the state-of-the-art. The literature overview involves the definition of literature sources, extraction, and synthesis of relevant research findings. The preliminary research will provide a fundamental understanding of symmetry in geometry, the types of symmetries, as well as the existing symmetry detection approaches. This phase also involves the study of CASD approaches related to 3D digital objects with a focus on solid CAD models. As most state-of-the-art CAD systems use the B-Rep technique for representing solid CAD models [10], the B-Rep technique will be studied to understand its basic concepts and mathematical background. Additionally, the scope of the preliminary research is to investigate the most suitable neutral file format (e.g., STEP, IGS, etc.) that will be selected as the input for the CASD. Based on that, a preliminary set of representative solid CAD models in form of

[2] The sequence of listing the objective and hypotheses depends on the area of research.

the selected neutral file format will be collected from the industry and/or online CAD databases. The preliminary set of CAD models CAD models will be studied and analyzed to define the types of numerical surfaces present in solid CAD models and to select the surfaces that will be covered in this research. Further, the preliminary set of CAD models will be used to define the certain groups of mechanical parts to which the research will be limited (e.g., milled and turned parts). In the end, the preliminary research will provide a clear definition of the research methodology, research goals, main research questions, and research hypothesis.

2. Based on the preliminary research, the first step of this phase is to propose a method for symmetry detection in solid CAD models that contain analytical as well as numerical surfaces. The aim is to propose a general method that can be implemented into different CAD systems. Hence, the proposed symmetry detection method will be conducted on CAD models in form of a neutral exchange file format using the topological and geometrical information of the B-Rep as input. In the second step, a computational environment for symmetry detection will be developed that will enable the implementation of the proposed method. For that purpose, a suitable CAD system will be selected, and the computational environment will be connected to it using its Application Programming Interface (API). Hereby, it is important to emphasize that the CAD system and its API will be exploited only as a "tool" for the implementation of the computational environment. The developed computational environment will be subjected to defect testing [29] on the preliminary collected CAD models. For that purpose, a test-debug-test implementation cycle will be used to check against the intended functionality and make modifications if the functionalities are not provided.

3. In this phase, a data set for validation will be collected which includes a significant number of representative solid CAD models gathered from the industry and/or online CAD databases. The proposed symmetry detection method will be validated using the Validation Square framework [30]. Then, the developed computational environment for symmetry detection will be subjected to validation using the collected data set for validation. The scope of validation of the computational environment includes the evaluation of the symmetry detection correctness in the CAD models, i.e., the correctness of identifying the corresponding planes and axes of symmetry. The correctness of detecting the symmetries of the computational environment will be evaluated manually by experts. Finally, the results of the validation phase will be compared with the research goals. Based on the knowledge gained during the validation phase, the advantages and possible shortcomings will be identified and analyzed, improvements will be proposed for the method and computational environment, as well as the proposal of future research based on final findings and conclusions.

Expected scientific contribution of proposed research *(suggested length: 500 characters with spaces)*

The expected scientific contribution of the research is:

1. A geometric-based method for symmetry detection in 3D CAD models that contain analytical and numerical surfaces.

2. A computational environment for symmetry detection in 3D CAD models that contain analytical and numerical surfaces.

List of literature cited *(no more than 30 references)*

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Total cost estimate of proposed research *(in kuna)*

75000 HRK

Proposed sources of funding for research

Type of funding	**Title of project**	**Project leader**	**Signature**

National funding	-	-	-
International funding	-	-	-
Other types of projects	-	-	-
Self funding	Yes		
Session of the Ethics Committee at which consent was given to the research proposal[3]	-		

Agreement of the mentor and the doctoral candidate to request for topic approval

I declare under responsibility that I agree with the topic whose approval is requested.

Signature

doc. dr. sc. Stanko Škec

Signature

Mladen Burić

Mladen Burić, mag. ing. mech.

STATEMENT

I declare under responsibility that I have not submitted a request for approval of an identical dissertation topic at any other university[4].

Zagreb, 01.06.2022.

Signature

Mladen Burić

Mladen Burić, mag. ing. mech.

Official stamp here

[3] Fill out only if needed
[4] Not required in case of dual doctorate (*Cotutelle de these*)