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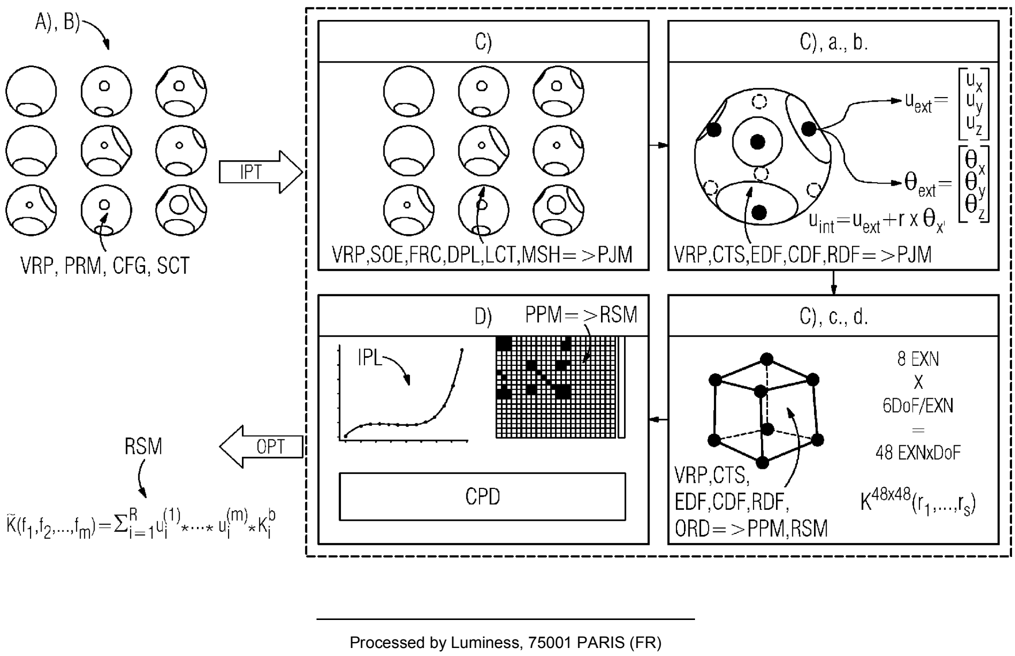
(54) METHOD FOR MODELLING VARIATIONS OF REPEATING PARTS OF A COMPONENT

(57) A computer-implemented method for modelling variations of repeating parts (VRP) of a component (CMP) comprising. To improve the modelling of components with repeating parts (VRP) with variations additional method steps are proposed as:
A) providing parameter sets (PRM) for part (VRP) configurations (CFG) of a plurality of different of said parts (VRP), wherein said parameters (PRM) of each parameter set (PRM) respectively define the part (VRP) configuration (CFG) of a part (VRP),
B) selecting a selection (SCT) of said part (VRP) configurations (CFG),
C) providing a part (VRP) model (MDL) for each part (VRP) configuration (CFG) of the selection (SCT), wherein said part (VRP) model (MDL) relates forces (FRC) and displacements (DPL) to locations of the respective part (VRP),
D) building an approximator (APX), wherein said approximator (APX) is provided for interpolating said part (VRP) models (MDL) to approximate a part (VRP) model (MDL) of a part (VRP) configuration (CFG) that doesn't belong to said selection (SCT) of said part (VRP) configurations (CFG).

FIG 3



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Description

FIELD OF THE INVENTION

[0001] The invention relates to a computer-implemented method for modelling variations of repeating parts of a component.

BACKGROUND OF THE INVENTION

[0002] Modelling variations of repeating parts of a component needs to be done often in performance of engineering tasks. For example, lattice structures, preferably of the lightweight type, become more popular in particular due to new production techniques like additive manufacturing, which enables easier creation of e.g. lightweight structures with variations of repeating parts of the component to be generated.

[0003] Lattice structures according to a narrower definition are containing beams that are connected at joints, most often by repeating a unit cell.

[0004] More general this invention is applicable to lattice structures which comprise also porous three-dimensional spatial structures formed and tessellated by unit cells with different topological geometries. This kind of lattice structure may be considered to belong to e.g. cellular structures (including foam structure, honeycomb structure and lattice structure).

[0005] If, for example, as a component a lattice structure with joints is considered these joints may be provided as variations of repeating parts and they may have a complex geometry. Such joints may conventionally be hard to simulate accurately without a large computational effort. Models required for industrially relevant applications may be highly detailed and may quickly become unfeasible regarding availability of computation power.

[0006] Lattice structures are generally simulated with the Finite Element Method (FEM). Here, the structure is subdivided ("meshed") into a mesh of simpler geometries called Finite Elements. These elements are more easily discretized and after assembly the full geometry is captured. During the post processing, the performance of the design can be gauged by looking at the simulation results. The total stiffness and mass are often used in topology optimization frameworks, stress concentrations decide the fatigue life of the structure and an eigenvalue analysis shows the dynamical behavior of the structure.

[0007] There are two types of mesh used for e.g. lattices. The first is a solid mesh: the lattice structure is subdivided into a large number of three-dimensional (3D) elements (e.g. Simcenter Nastran's CTETRA). Due to the geometrical complexity of lattices, a lot of these elements are often needed. This method can therefore be considered 'accurate but slow'.

The second mesh type is the one-dimensional (1D) mesh: every beam in the mesh is replaced by a beam element (for example Simcenter Nastran's CBAR). Fewer elements are thus needed, resulting in a much smaller computation time. A problem with this approach is that these beam elements are based on beam theory (Euler-Bernoulli beam theory, Timoshenko-Ehrenfest beam theory), which becomes inaccurate as the beams become thicker.

[0008] Aspects of lattice modelling are known from: M. Helou and S. Kara. Design, analysis and manufacturing of lattice structures: An overview. International Journal of Computer Integrated Manufacturing, 31(3):243-261, 2018. ISSN 13623052. doi:10.1080/0951192X.2017.1407456.

Another prior art publication is: G. Dong, Y. Tang, and Y. F. Zhao. A survey of modeling of lattice structures fabricated by additive manufacturing. Journal of Mechanical Design, Transactions of the ASME, 139(10), 2017. ISSN 10500472. doi: 10.1115/1.4037305.

[0009] Some teachings of these publications may be summarized regarding the field of the invention as follows. A major problem is that by replacing the beams with one-dimensional elements, every joint is replaced by a single point. However, these nodes contain a lot of stiffness and mass. In bending-dominated lattices, they also have a large influence on the fatigue life since that's where the highest stress occurs. There are some techniques in literature that try to mitigate this problem by increasing the beam thickness close to the joints, but this is more a pragmatic but less accurate solution. Further, there is no generally accepted way to determine by how much the thickness then needs to change. This method can therefore be considered "fast but inaccurate".

[0010] Currently, there exist methods for modelling variations of repeating parts of a component in particular for modelling a joint of a lattice structure. Such methods may benefit from improvements. It is one objective of the invention to improve the design process of components with variations of repeating parts.

SUMMARY OF THE INVENTION

[0011] Based on the prior art described above and the problems associated, the invention is based on the task of improving the design process of a component comprising variations of repeating parts, like lattice structures.

[0012] The object of the invention is achieved by the independent claims. The dependent claims describe advantageous developments and modifications of the invention.

[0013] In accordance with the invention there is provided a solution for the above described problems by the incipiently defined method comprising the additional steps:

A) providing parameter sets for part configurations of a plurality of different of said parts, wherein said parameters of each parameter set respectively define the part configuration of a part,

B) selecting a selection of said part configurations,

C) providing a part model for each part configuration of the selection, wherein said part model relates forces and displacements to locations of the respective part,

D) building an approximator, wherein said approximator is provided for interpolating said part models to approximate a part model of a part configuration that doesn't belong to said selection of said part configurations.

[0014] Components according to the invention may include lattice structures, porous three-dimensional spatial structures formed and tessellated by unit cells with different topological geometries, cellular structures like foam structures, honeycomb structures and the like.

[0015] Herein, variations of repeating parts mean structures comprising elements with similar function and similar geometry which may partly be identical and partly be different and which may be defined by a parameter set defining the respective part configuration. The method according to the invention uses these variations of repeating part as a new type of element which may be called a "Parameterized Superelement" which can be used more broadly for any structure containing a large amount of parts with a similar (but slightly varying) geometry.

[0016] Forces may include linear forces like tensile force, compression force, shear force and the rotational equivalent of linear force normally termed as moment, moment of force, rotational force or turning effect, torsional force. Forces may further comprise pressure, area forces, tensile stress, shear stress and compressive stress.

[0017] Concurrently, for lattice design it is highly attractive to use a topology optimization framework that decides to put the right lattice at the right place. However, optimization is an order of magnitude more complex and therefore expensive than simulation. Optimization of the highly detailed models required for industrially relevant applications therefore quickly becomes unfeasible.

[0018] This invention unlocks the possibility of fast and accurate simulation of e.g. lattices and may be even their subsequent optimization. This is done by the method steps defined by the claims - in other words by adopting a reduction and interpolation technique that simulates the e.g. lattice joints using so-called parametrized parts, respectively said "Parametrized SuperElements (PSE)". Furthermore, the invention may be applied to structures that contain a large amount of slightly varying structures. Currently available Finite Element Methods may be extended by the method according to the invention. Some examples of components respectively said structures according to the invention may be applied to (not limited to these):

- truss bridges and tower cranes, since they can be viewed as macroscale lattices;
- gas turbine rotors, since their blades all differ to prevent resonance; and
- ship hulls due to their large amount of plates, rivets, welds and beams in varying configurations.

[0019] According to a preferred embodiment of the invention the step of:

(this is step C) providing a part model for each part configuration of the selection, wherein said part model relates forces and displacements to locations of the respective part,
comprises for each part configuration of the selection the steps:

a. meshing a mesh of said part with solid elements,
b. generating a preliminary part model of the meshed part by relating forces and displacements to locations defining said solid elements through a first part stiffness matrix,
c. identifying constraints reducing the number of exterior degrees of freedom of movement by constrained degrees of freedom,
d. generating said part model by reducing the model order of said preliminary part model to the remaining exterior degrees of freedom by eliminating said constrained degrees of freedom of said first part stiffness matrix resulting in a reduced stiff-ness matrix,

and wherein step D) comprises building said approximator by interpolating the reduced stiffness matrixes to extract the reduced stiffness matrix of a part that doesn't belong to said selection of said part configurations.

[0020] According to another preferred embodiment of the invention, the repeating parts may be joints of a lattice structure.

[0021] According to another preferred embodiment of the invention, the selecting of step B) may be done by selecting all types of variations or by selecting only a subset of the whole variation plurality. In case of subset selection, the selection may be done randomly or by a systematic approach. The systematic approach may be done by varying parameters of the parameter set systematically. This variation may be done stepwise, maybe in equidistant steps along the range of the respective parameter if the range is limited with an upper and lower limit. Instead of equidistant steps logarithmic step widths or other step withs may be used, in particular if one parameter is not limited. The number of variations may be limited to a predefined number per parameter and the steps width may be defined by parameter range divided by number of steps. The resulting variation number may be the product of all number of respective parameter variants.

[0022] According to still another preferred embodiment of the invention, the step of reducing the model order is done using a Guyan reduction resulting in a reduced stiffness matrix. In computational mechanics, Guyan reduction, also known as static condensation, is a dimensionality reduction method which reduces the number of degrees of freedom by ignoring the inertial terms of the equilibrium equations and expressing the unloaded degrees of freedom in terms of the loaded degrees of freedom (GUYAN, J., Reduction of stiffness and mass matrices, R. , AIAA Journal 3 380--380 (1965) https://doi.org/10.2514/3.2874).

[0023] According to still another preferred embodiment of the invention, the interpolating of step D) uses Canonical Polyadic Decomposition. This tensor rank decomposition is one generalization of the matrix singular value decomposition applied to tensors [F. L. Hitchcock (1927). "The expression of a tensor or a polyadic as a sum of products". Journal of Mathematics and Physics. 6: 164-189].

[0024] The invention relates also to a computer-implemented method for optimization of a component comprising repeatedly carrying out an optimization step by the computer-implemented method for modelling variations of repeating parts of a component according to the preceding description and/or the features as defined by the claims for several variations of the component and subsequently comparing the results of the modelling with regard to predefined performance factors to identify starting configuration for the next optimization step. This optimization may be carried out as long as predefined target performance factors are reached. The optimization may also follow parallel tracks with different starting variations of the component and may interchange the variation features according to a predefined optimization strategy.

[0025] The invention relates also to an additive manufacturing method for generating a component with variations of repeating parts, wherein a design step comprises a method according to the above defined invention respectively to one of its embodiments, wherein a subsequent generating step is done according to a design generated by said design step.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] Embodiments of the invention are described, by way of example only, with reference to the accompanying drawings, of which:

Figure 1 shows a flow diagram of a method according to the invention.

Figure 2 shows a flow diagram of a method according to the invention for modelling a component.

Figure 3 shows a flow diagram of a method according to the invention for generating an approximator.

[0027] The illustration in the drawings is in schematic form. It is noted that in different figures, similar or identical elements may be provided with the same reference signs.

DESCRIPTION OF THE DRAWINGS

[0028] Figure 1 shows schematically a computer-implemented method for modelling variations of repeating parts VRP of a component CMP according to the invention comprising the steps of:

A) providing parameter sets PRM for part VRP configurations CFG of a plurality of different of said parts VRP, wherein said parameters PRM of each parameter set PRM respectively define the part VRP configuration CFG of a part VRP,

B) selecting a selection SCT of said part VRP configurations CFG,

C) providing a part VRP model MDL for each part VRP configuration CFG of the selection SCT, wherein said part VRP model MDL relates forces FRC and displacements DPL to locations LCT of the respective part VRP,

a. meshing a mesh MSH of said part VRP with solid elements SOE,

b. generating a preliminary part VRP model PPM of the meshed part VRP by relating forces FRC and displacements DPL to locations LCT defining said solid elements SOE through a first part VRP stiffness matrix SMX,

c. identifying constraints CTS reducing the number of exterior degrees of freedom EDF of movement by constrained degrees of freedom CDF,

d. generating said part VRP model MDL by reducing the model order ORD of said preliminary part VRP model PPM to the remaining exterior degrees of freedom RDF by eliminating said constrained degrees of freedom CDF of said first part VRP stiffness matrix SMX resulting in a reduced stiffness matrix RSM,

and wherein step D) comprises building said approximator APX by interpolating the reduced stiffness matrixes RSM to extract the reduced stiffness matrix of a part VRP that doesn't belong to said selection SCT of said part VRP configurations CFG,

E) generating a reduced component model RCP by using said approximator APX for several parts VRP of said component CMP and combining the resulting reduced stiffness matrices of these parts VRP with other models of elements of said component CMP.

[0029] Said approximator APX may be considered a Parametrized Superelement PSE.

[0030] Figure 2 shows a simplified illustration showing some steps of the method according to the invention for modelling a component CMP, here a lattice structure

LTS. The usage of the approximator APX respectively the Parametrized Superelement PSE according to the invention during lattice simulation, enables the efficient and accurate simulation of e.g. the diamond lattice DIA shown. The illustration shows the diamond lattice DIA structure being simplified to beams BMS and joints JNT (shown exemplary for one joint JNT). The joint JNT, being a specimen of the general part PRT according to the invention, is modelled as a Parametrized Superelement PSE and after doing so for all joints JNT the initial diamond lattice DIA structure is modelled. Finally, a reduced overall model OVM is obtained for the component CMP by combining all Parametrized Superelements PSE of the component CMP together with other element of the component. For the application of lattice structure simulation, the method according to the invention may be part of a procedure which may simulate the beams BMS with 1D elements but which models the joints JNT according to the invention as Parametrized Superelements PSE.

[0031] The invention is suitable to lattice structural design due to the large number of joints JNT with a complex geometry. The invention can also be applied to for example truss bridges (because such a bridge contains a large number of beams and joints JNT) and, more generally, any structure that contains many parts with a complex geometry (cars, planes, ...) which are similar but comprise variations being defined by the parameter sets PRM for part VRP configurations CFG. Essential steps of the procedure illustrated comprise:

1. the joint JNT is modelled by meshing it with solid elements
2. constraints CTS are added to reduce the number of exterior degrees of freedom (EDF).

According to a preferred embodiment connection faces of joints JNT of a lattice structure may be assumed to remain straight, which may result in a reduced number of remaining exterior degrees of freedom RDF, e.g. in six degrees of freedom per face. A subsequent reduction step may reduce the model order ORD to the exterior degrees of freedom EDF. This is done preferably by using a Guyan reduction (also known as substructuring, static condensation, substructuring, ...) which results in a reduced stiffness matrix similar to what would be achieved by an analytical element but applicable to more difficult geometries. Due to the computationally expensive reduction, a fast approximator APX on basis of a selection SCT of said part VRP configurations CFG may be built to extract the reduced stiffness matrix of a part VRP that doesn't belong to said selection. For a large number of joint configurations, the reduced matrices are generated. Then, they are interpolated in order to be able to extract the reduced stiffness matrix of a joint with parameters that are not previously simulated. In this case, the Canonical Polyadic Decomposition may be used since it eliminates all parameter dimensions, allowing for a 1D to 1D interpolation (e.g. illustrated in: https://www.tensorlab.net/doc/cpd.html).

[0032] Preferably a combination of the above steps enables an efficient calculation of the reduced stiffness matrix RSM that depends on the parameters of the complex geometry it represents.

[0033] Figure 3 shows steps of the method:

A) providing parameter sets PRM for part VRP configurations CFG and B) selecting a selection SCT of said part VRP configurations CFG as an input IPT for the next step,

C) a.&b.: providing a part VRP model MDL for each part VRP configuration CFG by meshing with solid elements SOE. Generating a preliminary part VRP model PJM of the meshed part VRP by relating forces FRC and displacements DPL to locations LCT defining said solid elements SOE through a first part VRP stiffness matrix SMX (steps a.(meshing a mesh MSH of said part VRP with solid elements SOE), b.(generating a preliminary part VRP model PJM of the meshed part VRP as a first part VRP stiffness matrix SMX)).

C) c.&d. Constrain with e.g. the straight face assumption and reduce to the remaining exterior degrees of freedom RDF. Generally, higher order face constraints can also be used to make a Parametrized Superelement PSE. E.g. 8 external nodes EXN and 6 degrees of freedom (DoF) respectively remaining degrees of freedom (RDF) result in a 48x48 stiffness matrix for the Parametrized Superelement PSE.

D) Build a fast approximator APX by repetition of the previous steps and interpolating IPL the reduced stiffness matrixes RSM to extract the reduced stiffness matrix of at least one part VRP that doesn't belong to said selection SCT of said part VRP configurations CFG. One technique used may be preferably static condensation also known as the superelement approach or substructuring. Afterwards an interpolation step is required to construct the approximator APX of the reduced stiffness matrix RSM provided as an output OPT of the method. A preferred implementation uses the Canonical Polyadic Decomposition CPD.

[0034] Although the present invention has been described in detail with reference to the preferred embodiment, it is to be understood that the present invention is not limited by the disclosed examples, and that numerous additional modifications and variations could be made thereto by a person skilled in the art within the definitions of the claims without departing from the scope of the invention.

[0035] It should be noted that the use of "a" or "an" throughout this application does not exclude a plurality, and "comprising" does not exclude other steps or elements. Also, elements described in association with different embodiments may be combined. It should also be noted that reference signs in the claims should not be construed as limiting the scope of the claims.

Claims

1. A computer-implemented method for modelling variations of repeating parts (VRP) of a component (CMP) comprising:

A) providing parameter sets (PRM) for part (VRP) configurations (CFG) of a plurality of different of said parts (VRP), wherein said parameters (PRM) of each parameter set (PRM) respectively define the part (VRP) configuration (CFG) of a part (VRP),
B) selecting a selection (SCT) of said part (VRP) configurations (CFG),
C) providing a part (VRP) model (MDL) for each part (VRP) configuration (CFG) of the selection (SCT), wherein said part (VRP) model (MDL) relates forces (FRC) and displacements (DPL) to locations of the respective part (VRP),
D) building an approximator (APX), wherein said approximator (APX) is provided for interpolating said part (VRP) models (MDL) to approximate a part (VRP) model (MDL) of a part (VRP) configuration (CFG) that doesn't belong to said selection (SCT) of said part (VRP) configurations (CFG).

2. Method according to claim 1, wherein step C) comprises for each part (VRP) configuration (CFG) of the selection (SCT) the steps:

a. meshing a mesh (MSH) of said part (VRP) with solid elements (SOE),
b. generating a preliminary part (VRP) model (PJM) of the meshed part (VRP) by relating forces (FRC) and displacements (DPL) to locations (LCT) defining said solid elements (SOE) through a first part (VRP) stiffness matrix (SMX),
c. identifying constraints (CTS) reducing the number of exterior degrees of freedom (EDF) of movement by constrained degrees of freedom (CDF),
d. generating said part (VRP) model (MDL) by reducing the model order (ORD) of said preliminary part (VRP) model (PPM) to the remaining exterior degrees of freedom (RDF) by eliminating said constrained degrees of freedom (CDF) of said first part (VRP) stiffness matrix (SMX) resulting in a reduced stiffness matrix (RSM),

and wherein step D) comprises building said approximator (APX) by interpolating the reduced stiffness matrixes (RSM) to extract the reduced stiffness matrix of a part (VRP) that doesn't belong to said selection (SCT) of said part (VRP) configurations (CFG).

3. A computer-implemented method according to claim 1 or 2, wherein the repeating parts (VRP) are joints (JNT) of a lattice structure (LTS)

4. A computer-implemented method according to claim 1, 2 or 3, wherein the selecting of step B) is a random selection (SCT).

5. A computer-implemented method according to at least preceding claim 2, wherein the step of reducing the model order (ORD) is done using a Guyan reduction resulting in a reduced stiffness matrix (RSM).

6. Method according to at least one of preceding claims 1 - 5, wherein said interpolating (IPL) of step D) uses Canonical Polyadic Decomposition (CPD).

7. Method according to at least one of preceding claims 1 - 6, comprising an additional step
E) generating an reduced component model (RCP) by using said approximator (APX) for several parts (VRP) of said component (CMP) and combining the resulting reduced stiffness matrices of these parts (VRP) with other models of elements of said component (CMP).

8. Additive manufacturing method for generating a component (CMP) with variations of repeating parts (VRP), wherein a design step comprises a method according to at least one of the preceding claims, wherein a subsequent generating step is done according to a design generated by said design step.

14. Computer-system (CPS) being adapted to carrying out a method according to at least one of preceding claims 1 - 6.

Amended claims in accordance with Rule 137(2) EPC.

1. A computer-implemented method for modelling variations of repeating parts (VRP) of a component (CMP) comprising:

A) providing parameter sets (PRM) for part (VRP) configurations (CFG) of a plurality of different of said parts (VRP), wherein said parameters (PRM) of each parameter set (PRM) respectively define the part (VRP) configuration (CFG) of a part (VRP),
B) selecting a selection (SCT) of said part (VRP) configurations (CFG),
C) providing a part (VRP) model (MDL) for each part (VRP) configuration (CFG) of the selection (SCT), wherein said part (VRP) model (MDL) relates forces (FRC) and displacements (DPL) to locations of the respective part (VRP),

D) building an approximator (APX), wherein said approximator (APX) is provided for interpolating said part (VRP) models (MDL) to approximate a part (VRP) model (MDL) of a part (VRP) configuration (CFG) that doesn't belong to said selection (SCT) of said part (VRP) configurations (CFG).

2. Method according to claim 1, wherein step C) comprises for each part (VRP) configuration (CFG) of the selection (SCT) the steps:

a. meshing a mesh (MSH) of said part (VRP) with solid elements (SOE),
b. generating a preliminary part (VRP) model (PJM) of the meshed part (VRP) by relating forces (FRC) and displacements (DPL) to locations (LCT) defining said solid elements (SOE) through a first part (VRP) stiffness matrix (SMX),
c. identifying constraints (CTS) reducing the number of exterior degrees of freedom (EDF) of movement by constrained degrees of freedom (CDF),
d. generating said part (VRP) model (MDL) by reducing the model order (ORD) of said preliminary part (VRP) model (PPM) to the remaining exterior degrees of freedom (RDF) by eliminating said constrained degrees of freedom (CDF) of said first part (VRP) stiffness matrix (SMX) resulting in a reduced stiffness matrix (RSM),

and wherein step D) comprises building said approximator (APX) by interpolating the reduced stiffness matrixes (RSM) to extract the reduced stiffness matrix of a part (VRP) that doesn't belong to said selection (SCT) of said part (VRP) configurations (CFG).

3. A computer-implemented method according to claim 1 or 2, wherein the repeating parts (VRP) are joints (JNT) of a lattice structure (LTS)

4. A computer-implemented method according to claim 1, 2 or 3, wherein the selecting of step B) is a random selection (SCT).

5. A computer-implemented method according to at least preceding claim 2, wherein the step of reducing the model order (ORD) is done using a Guyan reduction resulting in a reduced stiffness matrix (RSM).

6. Method according to at least one of preceding claims 1 - 5, wherein said interpolating (IPL) of step D) uses Canonical Polyadic Decomposition (CPD).

7. Method according to at least one of preceding claims 1 - 6, comprising an additional step
E) generating an reduced component model (RCP) by using said approximator (APX) for several parts (VRP) of said component (CMP) and combining the resulting reduced stiffness matrices of these parts (VRP) with other models of elements of said component (CMP).

8. Additive manufacturing method for generating a component (CMP) with variations of repeating parts (VRP), wherein a design step comprises a method according to at least one of the preceding claims, wherein a subsequent generating step is done according to a design generated by said design step.

9. Computer-system (CPS) being adapted to carrying out a method according to at least one of preceding claims 1 - 6.

FIG 1

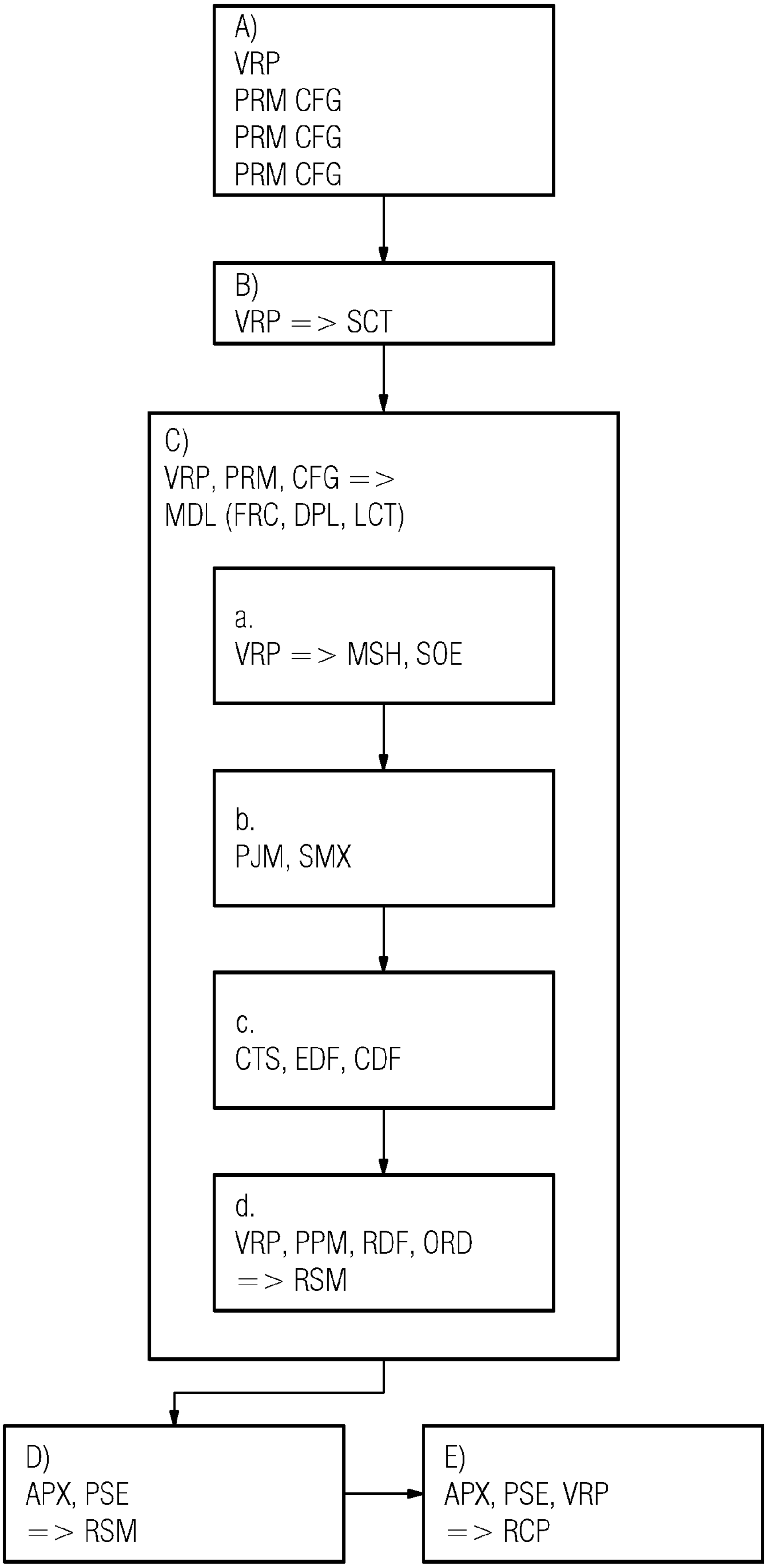

A)
VRP
PRM CFG
PRM CFG
PRM CFG
B)
VRP => SCT
C)
VRP, PRM, CFG =>
MDL (FRC, DPL, LCT)
a.
VRP => MSH, SOE
b.
PJM, SMX
c.
CTS, EDF, CDF
d.
VRP, PPM, RDF, ORD
=> RSM
D)
APX, PSE
=> RSM
E)
APX, PSE, VRP
=> RCP

FIG 2

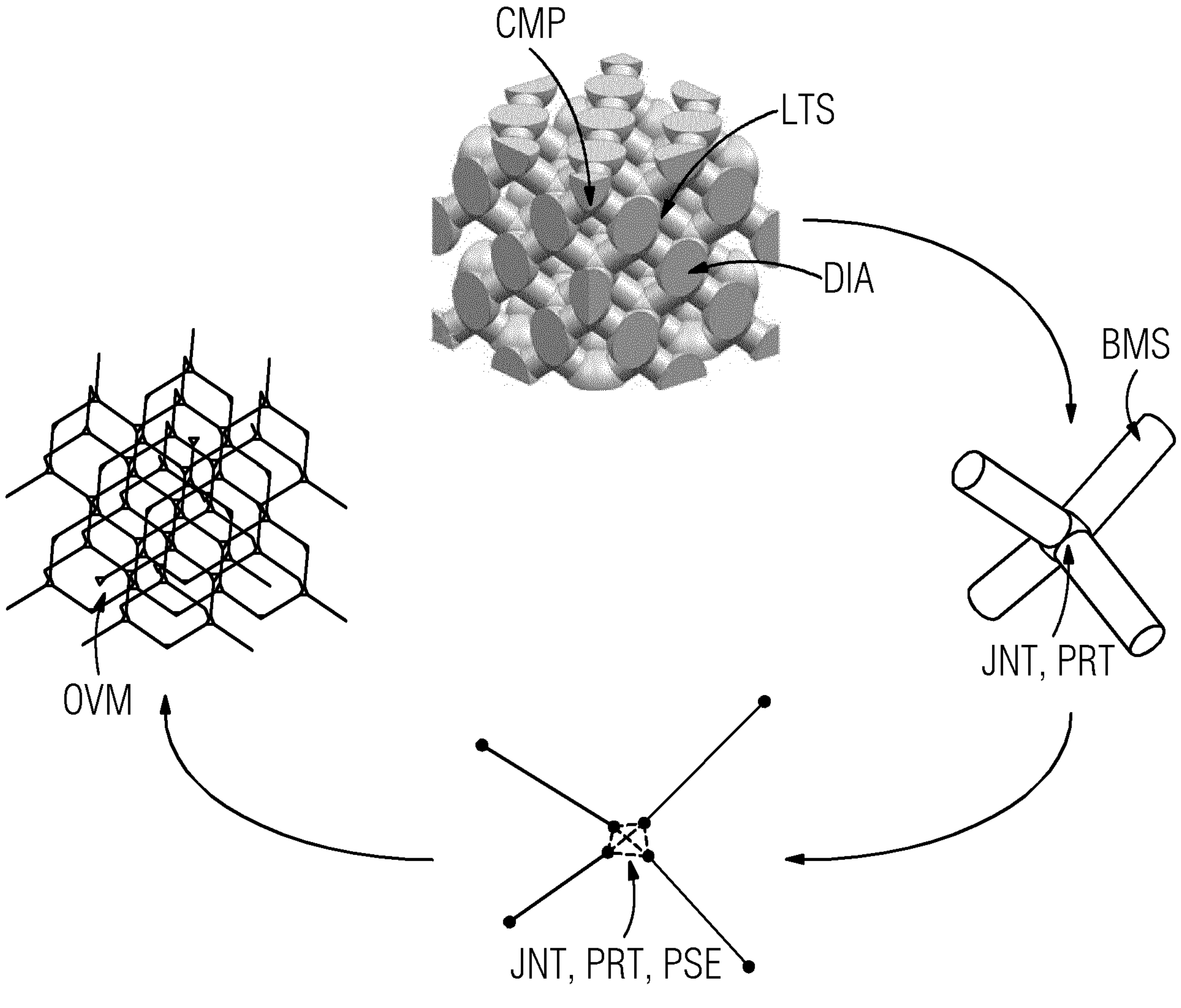
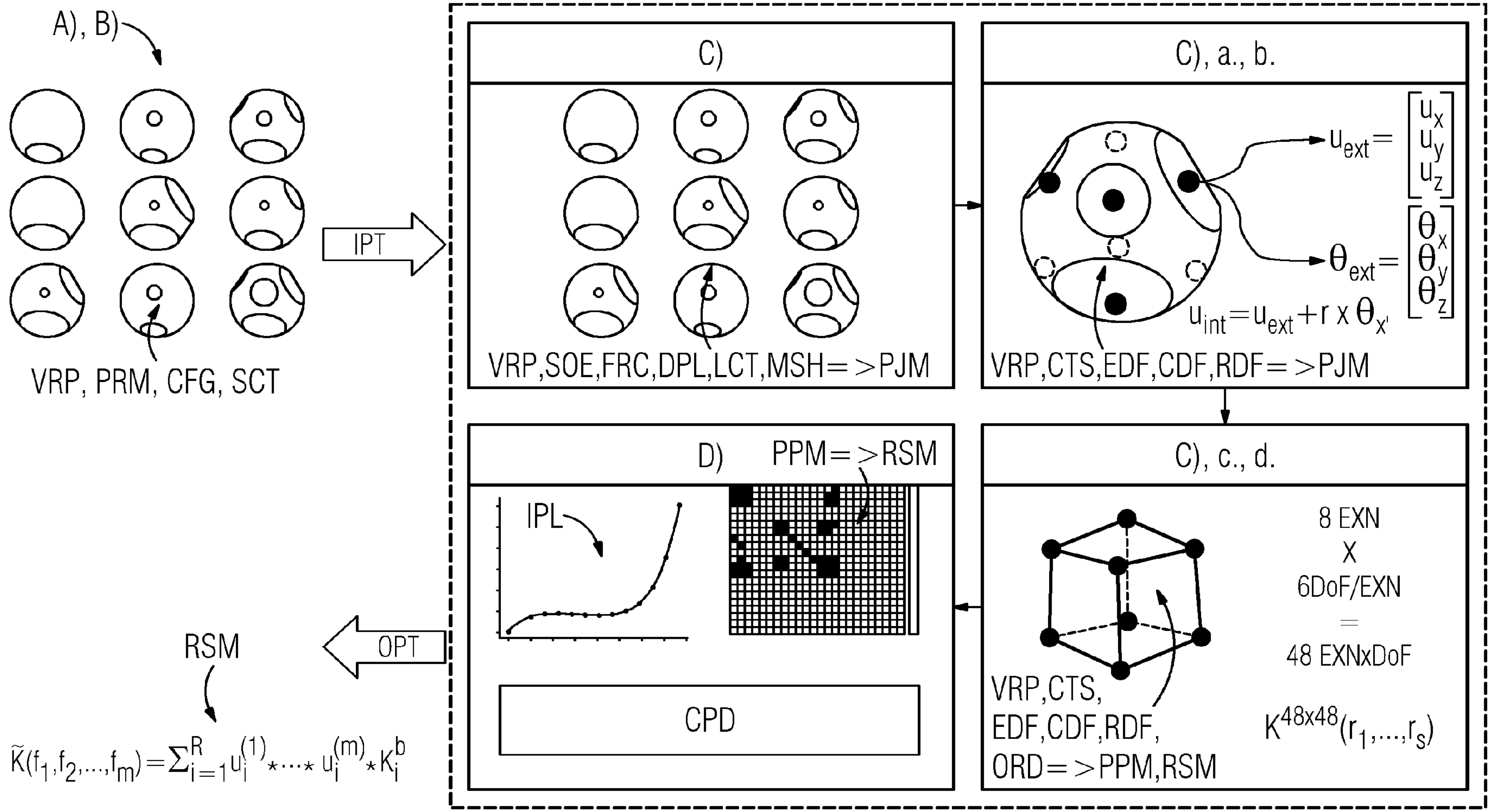


FIG 3


A), B)
VRP, PRM, CFG, SCT
IPT
C)
VRP,SOE,FRC,DPL,LCT,MSH=>PJM
C), a., b.
u_ext = [u_x u_y u_z]
θ_ext = [θ_x θ_y θ_z]
u_int = u_ext + r x θ_x'
VRP,CTS,EDF,CDF,RDF=>PJM
C), c., d.
8 EXN
X
6DoF/EXN
=
48 EXNxDoF
K^48x48(r_1,...,r_s)
VRP,CTS,
EDF,CDF,RDF,
ORD=>PPM,RSM
D)
PPM=>RSM
IPL
CPD
OPT
RSM
K̃(f_1,f_2,...,f_m)=Σ_{i=1}^R u_i^(1) *...* u_i^(m) * K_i^b

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EUROPEAN SEARCH REPORT

Application Number
EP 21 16 0989

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	Romeo Ryan ET AL: "Model Reduction of Self-Repeating Structures with Applications to Metamaterial Modeling : Proceedings of the 37th IMAC, A Conference and Exposition on Structural Dynamics 2019" In: "Structural Dynamics and Renewable Energy, Volume 1", 1 January 2019 (2019-01-01), Springer New York, New York, NY, XP055827629, ISSN: 2191-5644 ISBN: 978-1-4419-9716-6 pages 49-62, DOI: 10.1007/978-3-030-12243-0_9, * abstract; figure 1 * * section 2.2.1 * * page 1, paragraph 1 * * the whole document * -----	1-9	INV. G06F30/23 ADD. G06F113/10 G06F119/14
X	Speet Jeroen: "Parametric reduced order modeling of structural models by manifold interpolation techniques", , 10 November 2017 (2017-11-10), XP055827633, Retrieved from the Internet: URL:http://resolver.tudelft.nl/uuid:d1b77685-5b95-4991-bd41-7ce4cdd01605 [retrieved on 2021-07-26] * abstract; figure Figure 1.2 * * section 2.4, section 2.5.4 * * section 3.1: reduced model, chapter 4: interpolation * * chapter 5.3 application to lattice * * the whole document * ----- -/--	1-9	TECHNICAL FIELDS SEARCHED (IPC) G06F

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	16 August 2021	Dapp, Wolfgang

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	WU ZIJUN ET AL: "Substructure-Based Topology Optimization for Symmetric Hierarchical Lattice Structures", SYMMETRY, vol. 12, no. 4, 24 April 2020 (2020-04-24), page 678, XP055827623, ISSN: 2073-8994, DOI: 10.3390/sym12040678 * abstract; figure 1 * * additive manufacturing; page 1, paragraph 1 - paragraph 2 * * figures 9,12,15 * * the whole document * -----	1-9	
			TECHNICAL FIELDS SEARCHED (IPC)

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