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THE ADVANCED CAD MODEL OF A CARGO BIKE

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Abstract

This article describes a way to create a generative model using the example of a cargo bike model, which is a very simple object which can be used to present all important rules applied during creating generative models. Great attention was paid to the issue of model parameterization, which is an elementary thing in all modelling. Besides these aspects, it is also shown how to transform a parametric model into a generative model using programming languages. In the last part of the article, tests of correct working of model were included which also focused on the right position cyclist on the bike and shows how model of cargo bike could change its sizes thanks to correctly created generative model.

Introduction

During the design process of a mechanical system, the most common problems include (KUANG-HUA 2014):

– frequent design changes, especially at the beginning of work;

– an increase in the number and complexity of the required design changes, when the design process is carried out in large, distributed design groups implementing their subtasks in various engineering disciplines;

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– very often a simple change in one part causes an explosion of changes in related parts and assemblies, thus affecting assembly changes in the entire product;

– each time the changes made to the product model must meet the design constraints requirements.

In the 1960s, Ivan Sutherland developed a program called Sketchpad (SUTHERLAND 2003). Sutherland's idea for computer-aided drawing (later known as computer-aided design) was to first draw a sketch (a generic geometrical shape) and then add a set of dimensions. In fact, all current CAD systems use this concept. To increase the usability of the created geometric model, dimensions are divided into further dimensions with fixed values (fixed dimensions) and dimensions with floating values (open dimensions) (SHAH, MÄNTYLÄ 1995). It makes it easy to change the value of the selected dimensions depending on the respective needs. This model is called a parametric geometrical model (VUKAŠINOVIĆ, DUHOVNIK 2019, KALKAN et al. 2018). Parametric-based models allow for "reusable geometrical models" to be created. The creation process of parametric geometrical models requires experience and knowledge.

The advantages of parametric modelling include:

– the mechanical designer has the ability to define design variables by assigning dimensions to parts and creating geometric and form constraints between parts to build a parametric product model;

– in the case of a parametric product model, the designer can make changes to the model simply by modifying the values of the geometric dimensions. This allows, among others, to quickly identify potential collisions between elements in mechanisms;

– parametric product models allow designers to effectively search for alternative design solutions.

The next step in the development of CAD systems was the generative model. A generative model is intended to support the engineer in the course of routine activities (SKARKA 2006, 2011, COOPER et al. 1999, FOSTER 2019, BUONAMICI

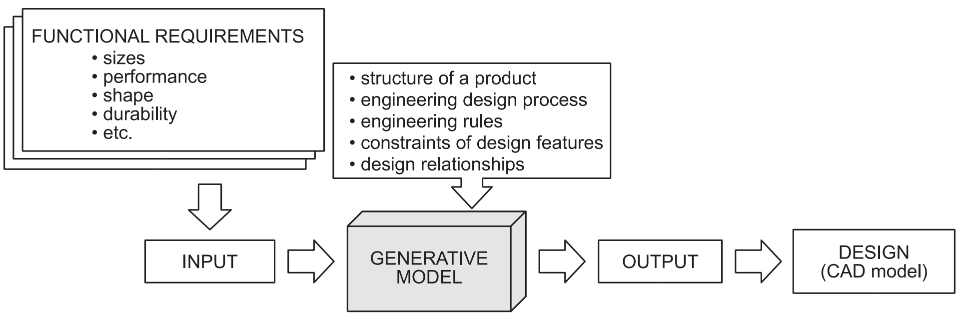

Fig. 1. Operation scheme for a generative model
Source: based on SKARKA (2006).

et al. 2020). To create such a model, a parametric geometrical model and the knowledge base associated with this model are needed. An applied parametric model is a generalized model, where the degree of generalization depends on the needs and use of such a model. Parametric models are used to create families of similar artefacts, while the generative model is a template of the engineering design process. It is a record of a certain class of artefacts, for which knowledge is acquired and stored in the form of relations between certain features and functional requirements (Fig. 1) (SKARKA 2006).

Creating generative models is a process related to such issues as: methodology of designing mechanical systems, computer science (practical knowledge of programming languages), CAx systems (including the ability to use an integrated programming language), and knowledge engineering. Due to the fact that the scope of issues is very wide, self-generating models should be created in interdisciplinary teams.

Methodology of creating generative models

Our own observations allow us to conclude that the process of creating parametric models can be presented as a sequence of some stages. Below, it is proposed to create generative models in four stages:

STAGE 1: Standardization of the work environment. The purpose of this step is to determine the parameters of the working environment, i.e. to select the type of the CAD software and, if necessary, the software for numerical calculations and simulations; development of report templates and drawing documentation; selecting the type of software, storage location and repository structure for files with models and reports, etc.

STAGE 2: Analysis of the design of the mechanical system. The purpose of this stage is to analyse the structure of a mechanical system in the context of creating a parametric model of this system. To this end, it is necessary to analyse the individual components with regard to their use in an assembly or assemblies in relation to their use in a product. The parametric model is driven by the values of some of the highlighted parameters (main dimensions) that can affect the values of other parameters. For this purpose, an analysis of documentation from the element/assembly design process should be used. As a result of this analysis, the structure of the parametric model and the relational relations between elements and assemblies should be defined. Then sets of main dimensions and characteristic features will be created, as well as a set of constraints on the values assumed by these dimensions and features.

STAGE 3: Create a parametric model. At this stage, a parametric model should be created using the functions and tools available in the selected CAx system. The results of the analysis carried out in STAGE 2 are important here. Knowledge of the identified features and dimensions is crucial because at this stage the computational models will be used to link the geometric, material, and dynamic features. The process of building parametric models can be presented as the following activities:

– analysis of the available parametric models and special tools available in the selected CAD program, intended for generating this class of models;

– in the case of using ready-made parametric models, adaptation of the obtained models to the adopted requirements and limitations;

– in case of the need to build own parametric models of parts – creating geometrical models of parts with a set of assigned parameter sets (main dimensions);

– if it is necessary to build own parametric models of assemblies, creating geometrical models of assemblies with a set of parameters sets assigned to them (main dimensions);

– development of calculation scripts for parametric models of assemblies and parts, with particular emphasis on the relations between dimensions belonging to these assemblies and parts, and development of calculation scripts for the adopted calculation models;

– if there is a need to use a dialog system for communication with the user – developing the form of graphical user interface dialog boxes with the use of built-in tools or programming libraries developed, e.g. in an external tool software.

The created parametric models can be the basis for the development of generative models. In this case, you can apply elements of knowledge-based design, ultimately integrating design knowledge into the CAD model.

STAGE 4: Verification of the model. This step is to verify the created parametric and/or generative model in relation to the adopted assumptions and constraints. The generated geometric form and the created program code for the adopted calculation model should be thoroughly checked. It is recommended to develop a test example to facilitate verification.

Cargo bike advanced CAD model

The cargo bike model is a very good example of the utility of designing generative models. Every man and woman have different physiques and needs (RIGGS 2016). It is possible to design a generative model of cargo bike and provide the user with a form, where the user will be able to set information about his height, data about goods which he would like to transport, or the number of people who would be passengers of this bike, and based on these data algorithms, the model of cargo bike will be the most compatible with information which were set by the user in form.

Everyone has different body sizes, so it seems normal for not everyone to be comfortable riding on all sizes of bikes. Of course, there are parts that can be regulated, such as seat height, but the first step in choosing a bike should be to fit the correct frame size. In practice, there is an important dimension that allows us to choose the right frame size. This is the height of the crotch, which is the dimension from the floor to the crotch. This value should be multiplied by a special coefficient which depends on the type of bike for which the frame is chosen. In this project, a frame for mountain bike (MTB) was created, so in this case the coefficient was 0.57. The received value is the ideal size of the seat tube, so due to this we can read the rest of the important dimensions from the table on the producer's website. Table 1 shows an example of this.

Table 1

Frame sizes for MTB bike

Element	Sizes [cm]					
	XS	S	M	L	XL	XXL
Seat tube	34.5	40	44	48	52	56
Frame tube	54.5	58.5	61	63.5	66	68.5
Head tube	9.5	10.5	11.5	12.5	13.5	14.5
Bottom tubes of rear triangle	44					
Seat tube angle	73					
Head tube angle	70					

Source: based on PRZECHODZIEŃ (2020).

Diagram of a generative CAD model

Figure 2 shows a diagram of the generative model developed. The source of parameters for frame sizes from each type of bike – Long John and Trike – is a part file named "GLOBAL PARAMETERS.ipt". Then each type is shaped separately. Based on the three main dimensions of the cargo – width, length, and height – the dimensions of the cargo space are calculated. It was assumed that the method of fixing the wheels to the frame and the wheel sizes will be common for each type of bicycle. Depending on the bike type selected, the main assembly is made in "00_cargobike_longjohn_iassembly.iam" or "00_cargobike_trike _iassembly.iam" and then this assembly is read by the parent assembly model, a file named "#Generative model of cargo bike.iam". This file has an attached script and a dialog form. The script contains the functions necessary to control the dialogue, as well as functions to calculate the dimensions of the frame, cargo space, and other parts. The form "Cargo bike frame selection" has been created to control the dialogue.

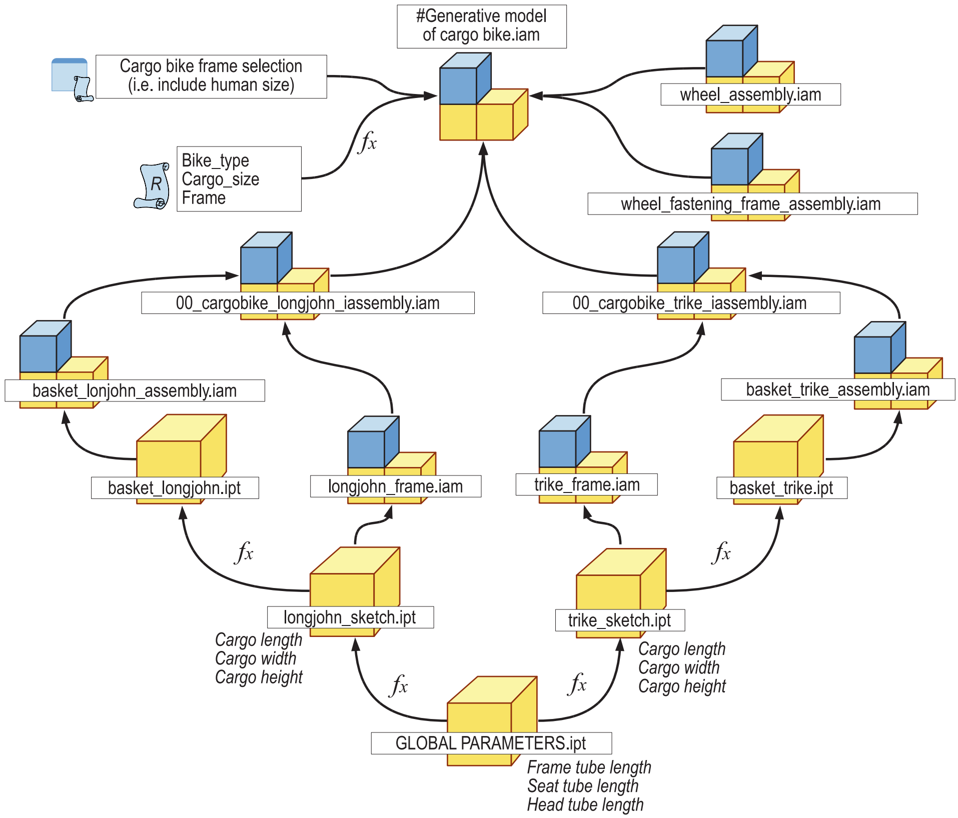

Fig. 2. Generative model diagram

Generative model of a cargo bike

The first step in creating the right generative model is to prepare the correct parametric model (SHIH 2019, LANCASTER 2020). We can do it with a standard modelling method, which we use during our daily work. It is only important to find one or a few significant dimensions which will define other dimensions of the model. In case of creating cargo bike model this, the most important dimensions were length of seat tube,, head tube and frame tube. So if there are only three control variables which will be responsible for all bicycle figure in part for cyclist, this is a good idea to put them into the separate model file and in the next steps of modelling relate to them. So, as we can see in Figure 3, a file with only three parameters in the list was created.

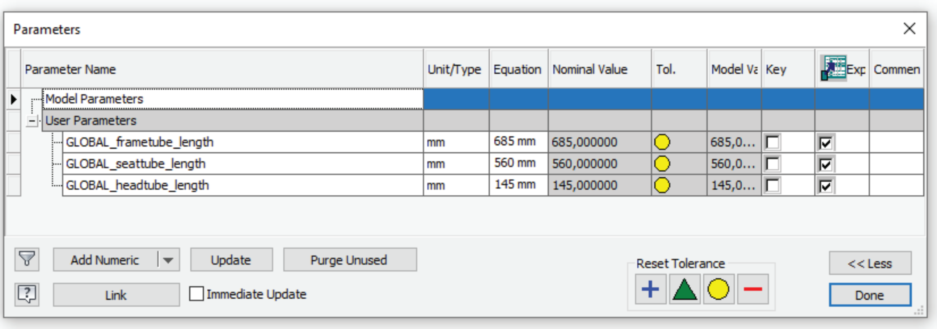

Fig. 3. Global parameters

Thanks to this simple operation, we obtained the possibility to import this parameter into any model file where it will be necessary. After this, I could create parameters in the file with a sketch of the bicycle. In the next steps, only these 3 variables were used to obtain any other tube figure of all the cargo bikes. The list of parameters and mathematical operations performed is shown in Figure 4.

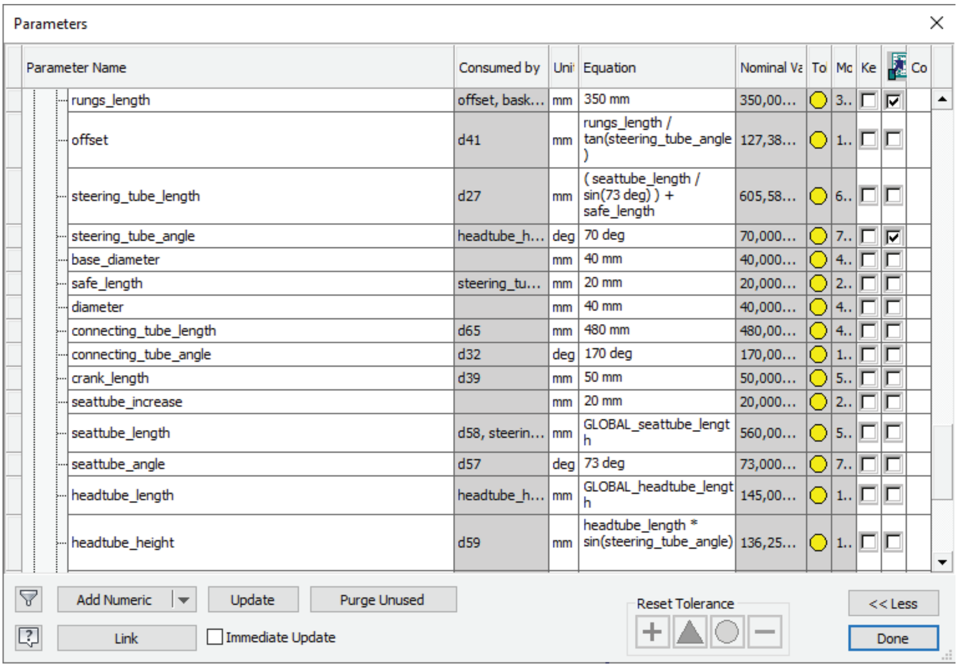

Fig. 4. List of parameters in the sketch file

In this project, the frame generator (Autodesk. 2020, MUNFORD 2016, SHIH 2019) was used. This is a tool offered by Autodesk Inventor that allows to replace the sketch with tubes models and create simple connections between these elements (LANCASTER 2020). Therefore, this is something which will be perfect to use in a bicycle model. The very important thing was also right and the full constraint of the sketch because during the model work all of these elements will be changing all the time. Thanks to the use of defined parameters and sketch constraints, a drown model of a cargo bike could be built on a few planes in three-dimensional space. It is visible in Figure 5. After this, it was possible to create a frame assembly using the aforementioned tool.

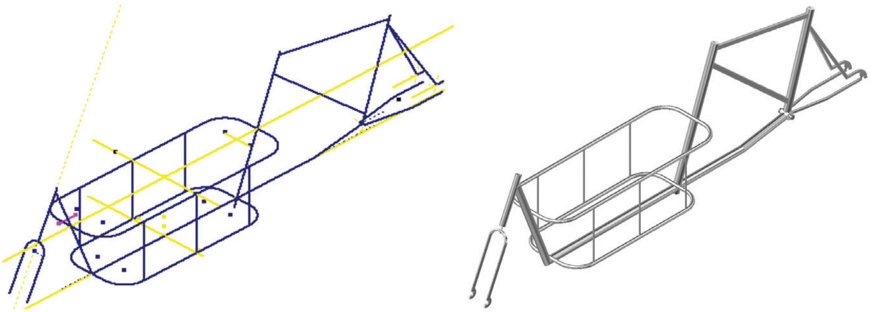

Fig. 5. Sketch and frame construction of a cargo bike

After the frames were fitted with the operations mentioned above, typical bicycle accessories and instruments such as wheels, saddle, steering wheel, and pedals were added. Normally, the Long-John bike also has a rod connecting the handlebar to the front wheel, which allows its turning, but this element was not included in the model as it is a less important accessory in the context of the main topic. So there were prepared in all 8 assemblies which differ from each other generally only in the form of a basket, but thanks to this and the option iAssembly in Autodesk Inventor it is simple to switch models between these which are actually required by the user. All of these assemblies are presented in Figure 6.

The very important item was the basket, which is used to transport goods and people. This is an accessory which has to cooperate with frame, so its dimension had to be correctly parametrized and addicted to dimensions of frame.

So, if we have prepared a parametric model now, we can focus on the most important part of generative models – the computer program and forms. The first step was to import all bicycle assemblies into one large assembly and turn off their visibility. In assumptions of the project program, the visibility between these models will be changed according to the information which will be put in the form of the user. The very good idea is also to create a list of control parameters that will cooperate with the script and will be used to store variable values. These things are visible in Figure 7.

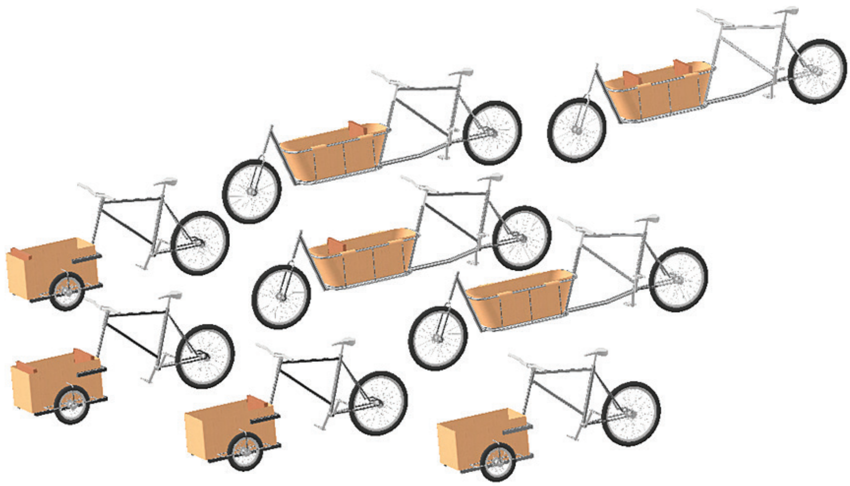

Fig. 6. All models of the cargo bike

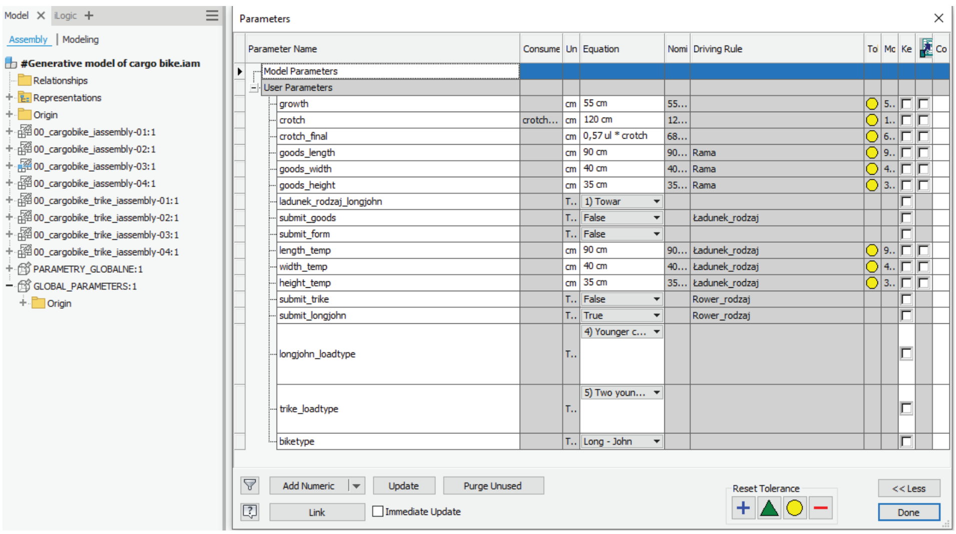

Fig. 7. Imported models and list of control parameters

After preparing the main model and parameters, it was possible to start programming all the generative parts. The first thing that was to be done was design the user form which will be responsible for the interaction between the user and the model. To implement these assumptions, the form was split into steps, and the first of them is selection of the type of cargo bike. There are only two options (for long john or trike) and each of them activates another section of form that is responsible for this type of cargo bike which the user has chosen. All this form was presented in Figure 8.

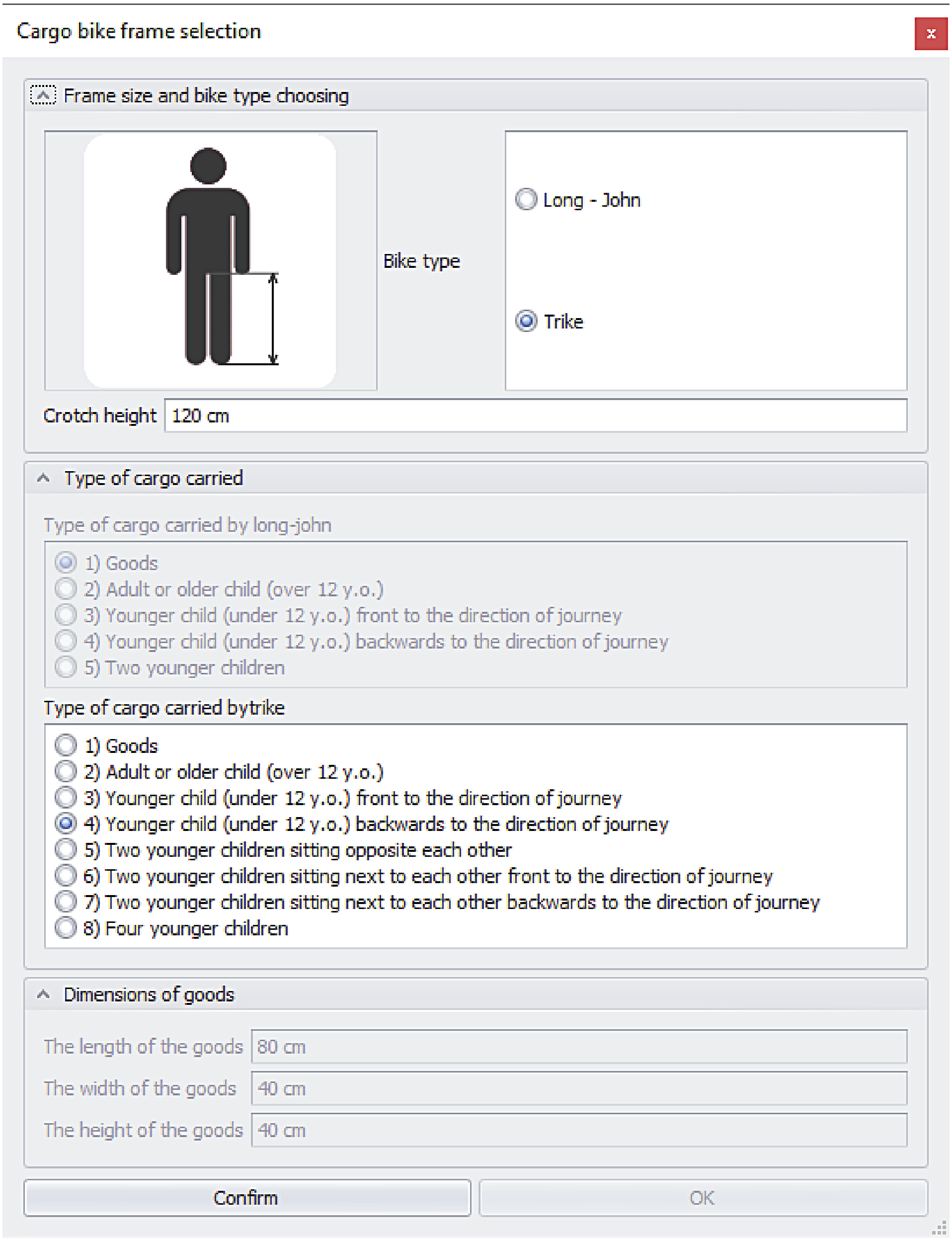

Fig. 8. Cargo bike selection form

Right working of this form and model was possible thanks to using rules which are written in Visual Basic of Applications language.

Rules *Goods_type* and *Frame* are the most important rules in this model. They are responsible for switching bikes, assigning values to appropriate parameters, and generating the final version of the cargo bike. *Button_active* is a rule that activates the 'OK' button in the form after entering the user's input data. Rule *Bike_type* allows for dynamic switching between suitable fields in form according to chosen by user type of cargo bike. *Form_open* is used as a trigger for opening the form at the moment when the model is opened.

Verification tests

After creating all elements that were described above, it was necessary to check if the generative model fulfils its function. To show the differences in the position of the human body on a bicycle with different frame dimensions, a dummy model was used (Fig. 9).

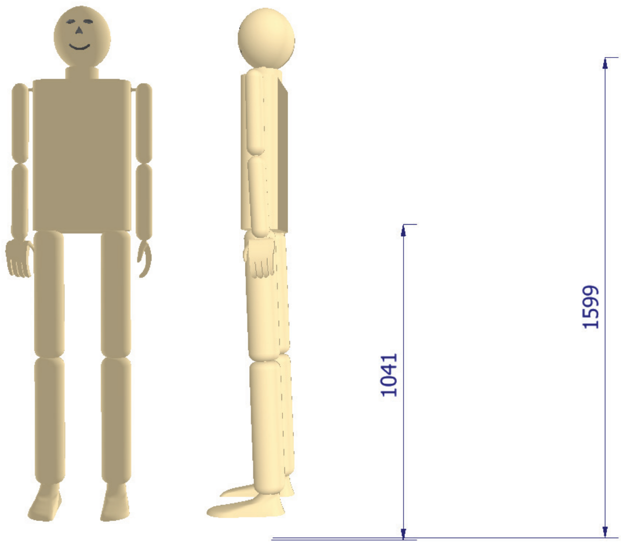

Fig. 9. Dummy model used to tests

In each of the tests, it had exactly the same dimensions, which was to show its current position. So, the dummy model was placed on the bike with the smallest frame. As you can see in Figure 10, the bike was too small for the person with a body similar to this dummy. It was not comfortable and ergonomic for cycling. After changing the crotch to a larger dimension, this situation was slightly better, but it was still not in the correct position (Fig. 11).

So, in the last test, the real value of the crotch dimension of the dummy was given. It was not surprising that in this case the frame size was acceptable for the body dimensions of the dummy (Fig. 12).

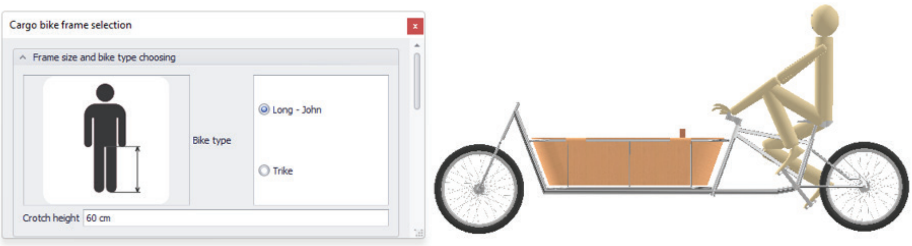

Fig. 10. Test with a dummy in the smallest frame

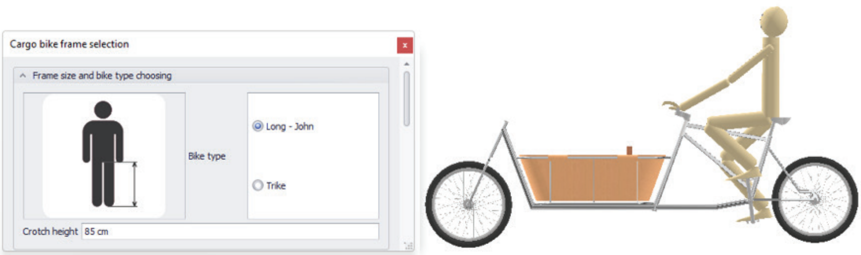

Fig. 11. Test with a dummy in the medium frame

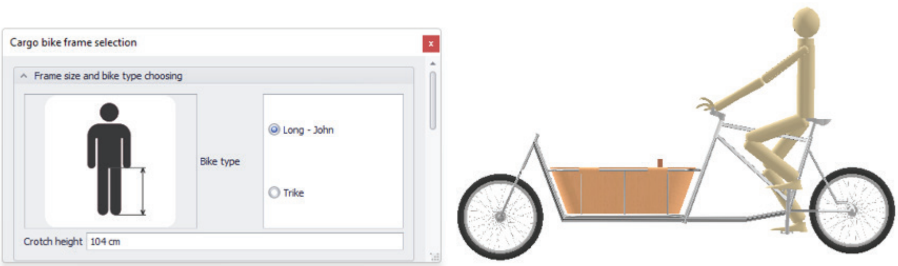

Fig. 12. Test with a dummy in the correct frame

Also, in the parameter lists there are changes which are submitted by the work of rules. In Figure 13 and Figure 14 the differences between the global parameters (which are the most important parameters in this model) were shown depending on the given height of the crotch. All operations and changes to parameter values take place in the background during the execution of the generative model functions, while the user entered only one piece of information in the form.

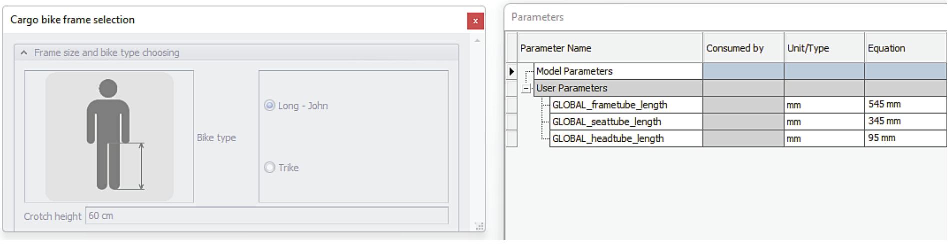

Fig. 13. Value of global parameters when a small crotch height value was given

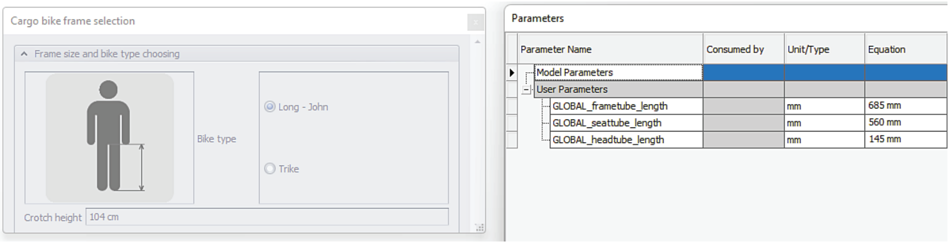

Fig. 14. Value of global parameters when a small crotch height value was given

Summary

Generative models are created using parametric models. Parameterization allows you to create reusable geometric models (SHAH, MÄNTYLÄ 1995) or structure families. The process of developing parametric models requires experience and knowledge about potentially other applications of the constructed system.

The input parametric model is a generalized model. The scope of the generalization depends on the needs and purpose of such a model. Parametric models are suitable for creating families of structures for a predetermined structural form. On the other hand, the auto-generating model is a construction template, a record of a class of technical objects, taking into account the design knowledge identified especially for their needs.

The main disadvantages of generative models are the following:

1. Their flexibility and use depend on the scope and quality of the integrated knowledge. In the case of newly created structures, the constructor, while selecting the design features, focuses solely on solving the current problem. At the same time, it does not deal with generalizing its actions, which should be treated as typical behavior. Only creating many similar solutions allows the constructor to refer to his experience and attempt to generalize the developed methods. This is a known issue and can only be mitigated; it cannot be eliminated. Therefore, autogenerating models are difficult to develop in innovative structures, although the knowledge contained therein may be the basis for the development of such structures.

2. The incorrect parameterized input geometric model (of parts and assemblies) causes many problems related to the resulting limitations in shaping geometrical features. Before the parameterization process of the geometric model, the basic parameters of the product, in particular the ranges of the main dimensions, should be clearly defined and then related to the design features. During the parameterization process, one should refer to experience (self or other constructors), because parameterization of geometric models is a complex creative process.

3. Although the methodologies for generating generative models are not related to specific CAx systems, their implementation must take into account the limitations imposed by a given CAx system. The most noticeable here is the lack of a format for recording geometric models, recognized by leading CAx software producers, along with the knowledge that was used to generate these models. The greatest hopes are associated with the STEP format, which according to the standard allows for the recording of information related to all phases of a product's existence.

References

Autodesk. 2020. *Frame Generator overview*. https://knowledge.autodesk.com/support/inventor/learn-explore/caas/CloudHelp/cloudhelp/2020/ENU/Inventor-Help/files/GUID-953F560A-C2D3-4031-8348-762054C7C779-htm.html (access: 09.11.2020).

Buonamici F., Carfagani M., Furferi R., Volpe Y., Governi L. 2020. *Generative Design: An Explorative Study*. Computer-Aided Design and Application, 18(1): 144-155.

Camba J.D., Contero M., Company P., Hartman N. 2020. *The Cost of Change in Parametric Modeling: A Roadmap*. Computer-Aided Design and Application, 18(3): 634-643.

Cargocycles. 2020. *Long-John cargo bike photography*. https://cargocycles.com.au/wp-content/uploads/2020/02/babboe-mini-vlt2020-2.jpg (access: 09.11.2020).

Cooper S., Fan I., Li G. 1999. *Achieving competitive advantage through knowledge-based engineering: a best practice guide*. Prepared for the Dept. of Trade and Industry by Dept. of Enterprise Integration, Cranfield University.

Foster D. 2019. *Generative Deep Learning*. O'Reilly Media Inc., Sebastopol.

ISO 10303: Industrial automation systems and integration – product data representation and exchange. Standard for the Exchange of Product model data (STEP). 2007. International Organization for Standardization. Mishra R.S., Mahoney M.W. Friction Stir Welding and Processing, 1st ed. ASM International, Materials Park, Ohio.

Kalkan O.E., Fatih O., Altunişik A. 2018. *Applications and usability of parametric modeling*. Journal of Construction Engineering, Management & Innovation, 1. http://doi.org/10.31462/jcemi.2018.03139146.

Kuang-Hua C. 2014. *Product Design Modeling using CAD/CAE: The Computer Aided Engineering Design Series*. Elsievier, Amsterdam.

Lancaster M. (2016) *Inventor Frame Generator Skeleton and Model Structure*. SYNERGIS Engineering Desing Solutions. https://synergis.com/2016/01/14/inventor-frame-generator-skeleton-and-model-structure (access: 08.11.2020).

Munford P., Normand P. 2016. *Mastering Autodesk Inventor 2016 and Autodesk Inventor LT 2016: Autodesk*. Sybex Inc., Hoboken.

Przechodzień Ł. 2020. *Rozmiar ramy rowerowej – jaki wybrać?* Rowerowe porady. https://rowe-roweporady.pl/rozmiar-ramy-rowerowej (access: 07.11.2020).

RIGGS W.W. 2016. *Cargo Bikes as a Growth Area for Bicycle vs. Auto Trips: Exploring the Potential for Mode Substitution Behavior*. Transportation Research. Part F. Traffic Psychology and Behaviour, 43: 48-55. http://doi.org/10.1016/j.trf.2016.09.017.

SHAH J.J., MÄNTYLÄ M. 1995. *Parametric and Feature-Based CAD/CAM: Concepts, Techniques and Applications*. A Wiley – Interscience publication, Hoboken, New Jersey.

SHIH R. 2019. *Parametric Modeling with Autodesk Inventor 2020*. SDC Publications, Mission.

SHIH R.H. 2019. *Learning Autodesk Inventor 2020: Modeling, Assembly and Analysis*. SDC Publications, Mission.

SHKIH R.H. 2019. *Parametric Modeling with Autodesk Inventor 2020*. SDC Publications, Mission.

SKARKA W. 2006. *Knowledge acquisition for generative model construction*. In: *Leading the Web in concurrent engineering: next generation concurrent engineering, Frontiers in Artificial Intelligence and Applications Series*. Eds. P.S. Ghodous, R. Dieng-Kuntz, G. Loureiro. IOS Press, Incorporated, p. 263–270.

SKARKA W. 2011. *Ontology-based intelligent personal assistant*. In: *New World Situation: New Directions in Concurrent Engineering*. Eds. J. Pokojski, S. Fukuda, J. Salwianski. Proceedings of the 17th ISPE International Conference on Concurrent Engineering, Advanced Concurrent Engineering, Springer London, Limited, p. 267–274.

SOBIESZCZANSKI-SOBIESKI J., MORRIS A., VAN TOOREN M. 2017. *Multidisciplinary Design Optimization Supported by Knowledge Based Engineering*. Wiley, Hoboken, New Jersey.

SUTHERLAND I.E. 2003. *Sketchpad: A man–machine graphical communication system*. Tech. Rep. UCAMCL-TR-574, Computer Laboratory, University of Cambridge, Cambridge MA.

Trike cargo bike photography. 2020. Cargocycles. https://cargocycles.com.au/wp-content/uploads/2018/02/babboe-big-01-65-1.jpg (access: 09.11.2020).

VUKAŠINOVIĆ N., DUHOVNIK J. 2019. *Advanced CAD Modeling. Explicit, Parametric, Free-Form CAD and Re-engineering*. Springer Nature, Switzerland AG.