Complete and Automated Generation of Configurable Virtual Prototypes of Products Based on Parameterization Tools and Rules. Application to a Case Study

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Abstract. In engineering, the 3D model of a product is essential. A 3D model allows making modifications by editing the characteristic modeling functions, which implies knowing in detail the process followed in the modeling. In addition, the flexibility in the configuration is limited, since the modifications are made on geometry and parameters that are dependent on each other. In this work, a parametric modeling approach allows the generation of 3D models with different specifications by modifying a reduced number of parameters. To demonstrate the functionality, an application has been developed, using Autodesk Inventor iLogic, for the modeling of an engine with V-cylinder arrangement. Taking as input key parameters (number of cylinders,…), it can generate virtual prototypes with different configurations, facilitating the selection of the best product configuration by allowing to evaluate different alternatives.

Keywords: CAD · 3D models · Parameterization · Product configuration · Rules

1 Introduction

CAD tools are a basic element in engineering, facilitating the design and management of products and industrial facilities in all phases of their development, as well as communication between the people involved in the process [1].

For engineering students, CAD tools bring them closer to the professional world [2], simulating real devices with resources within their reach (personal computers and educational licenses of CAD tools provided by universities), increasing their motivation and learning [3] by relating theoretical concepts and practical application, improving the understanding of different mechanisms.

In the first years of engineering degrees, students receive technical drawing courses to improve their spatial vision and become familiar with the language of engineering drawings. These courses usually focus on the use of pencil and paper representation

systems and 2D CAD tools. In later courses it is common to be introduced to 3D modeling tools [4] and even simulation [5].

In order to optimize the use of 3D CAD applications and facilitate the understanding of real mechanisms, the 3D models used must allow changes in their geometry without having to restart the project again. The modeling strategy if fundamental for this [5]. There are many ways to model the same component, but to create optimal 3D models it is necessary to perform a parametric design that allows controlling, with a few parameters, the geometry of the component [6].

The objective of this work is to establish a parametric modeling methodology, applied in this case to combustion engines (although it can be extrapolated to other engineering mechanisms) that allows the automatic generation of 3D models with different specifications by modifying a few parameters, which allows students to immediately have the 3D model of a new engine for their study, without having to perform the modeling again from scratch.

In this work (the result of a TFM supervised by professors of the Department of Graphic Engineering of the UPV for the qualifying master's degree in Industrial Engineering) the iLogic tool of Autodesk Inventor Professional has been used. iLogic allows the implementation of rules applicable to the parameters that govern the functionality of the engine and affect the modeling operations.

Section 2 presents the set of parameters that define the specifications and how the geometrical parameters are derived from them, Sect. 3 shows some of the relationships and rules implemented, Sect. 4 shows the results and Sect. 5 presents the conclusions.

2 Main Parameters and Geometrical Parameters

First, the main parameters (those that, within a certain range of values, will allow different configurations available) will be determined. From them, the geometric parameters used in the modeling will be derived. Table 1 shows the main parameters used with the ranges of values considered. With the different levels available for selection, there are more than 7000 possible configurations.

Table 1. Main engine parameters.

Parameter	Description	Units	Range of values
VT	Total cylinder capacity	Cubic centimeters (cc)	[1000, 7000]
z	Number of cylinders	–	[4, 12] (even number)
cd	Stroke ratio	–	[0.7, 1.4]
α	V angle	Sexagesimal degrees (°)	60°, 90° and 120°

Figure 1 shows an engine with a specific configuration. To reduce complexity, only the essential components have been modeled and the details have been simplified.
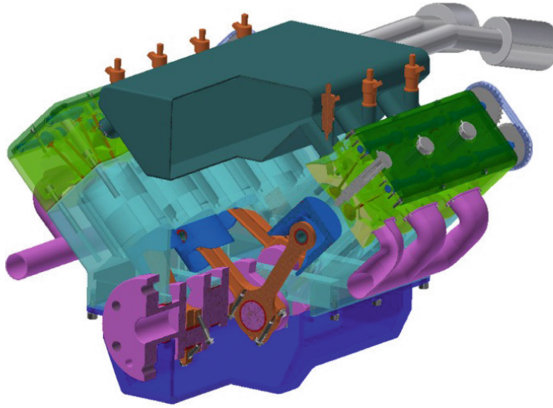
Fig. 1. Engine with 8-cylinder V configuration at 90° with 4000 cc and stroke ratio 1.
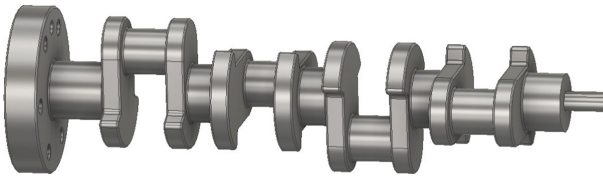

Fig. 2. Engine crankshaft in Fig. 1.

Figure 2 shows the crankshaft modeled with the specifications corresponding to the engine in Fig. 1. Together with the engine block, this is the component whose modeling is more dependent on the main parameters selected.

The geometrical parameters of the engine (some of them are shown in Table 2 and Fig. 3) depend on the main ones and are obtained from them with equations that are implemented by means of Autodesk Inventor iLogic rules.

Table 2. Most important geometrical parameters of the engine.

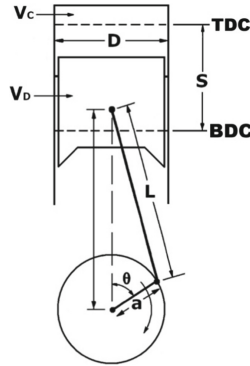| Parameter	Description	Units
VD	Unitary capacity	Cubic centimeters (cc)
S	Stroke	Millimeters (mm)
D	Piston diameter	Millimeters (mm)
Ap	Piston section	Square Millimeters (mm^2)
a	Crank distance	Millimeters (mm)
L	Connecting rod length	Millimeters (mm)
γ	Crank/rod ratio	–

Fig. 3. Relationship between geometric parameters.

The unitary capacity (1) is the volume displaced by the piston. It is obtained from the total cylinder capacity and the number of cylinders.

$$V_D = V_T/Z \tag{1}$$

The stroke (2) is the distance from top dead center (TDC) to bottom dead center (BDC). It is obtained from the unitary capacity and the piston cross-section.

$$S = V_D/A_p \tag{2}$$

The piston diameter (3) is obtained from the stroke and the stroke ratio.

$$D = S/cd \tag{3}$$

The piston cross-section (4) is obtained from the diameter.

$$A_p = \left(\pi \cdot D^2\right)/4 \tag{4}$$

From Eqs. (2), (3) and (4) the diameter (5) and the stroke (6) are obtained.

$$D = \left(\frac{V_D \cdot 4}{\pi \cdot cd}\right)^{1/3} \tag{5}$$

$$S = D \cdot cd \tag{6}$$

The crank (7) transforms the translational motion of the piston into the rotational motion of the crankshaft. It is the distance between the crank pin shaft (where the connecting rod heads are housed on the crankshaft) and the crankshaft axis.

$$a = S/2 \tag{7}$$

The connecting rod length (8) is the distance between the crank pin axis and the central axis of the connecting rod foot. It is calculated from the parameter γ and the crank. γ is set between 0.2 and 0.4 and in this work has been used $\gamma = 0.25$.

$$L = a/\lambda = (S/2)/0.25 = 2 \cdot S \tag{8}$$

Other geometrical parameters are obtained directly from the above. Table 3 shows some of the piston parameters derived from the diameter.

Table 3. Secondary geometrical parameters of the piston.

Parameter	Usual range	Selected value
Piston height	(0.6–1.5) D	1.2 D
Distance from pin to piston head	(0.3–0.6) D	0.6 D
Segment height	(0.02–0.025) D	0.025 D
Piston pin diameter	(0.2–0.4) D	0.26 D

3   Relationships and Rules

All the components modeled in this work have been parameterized according to the main parameters, but only a few of the relationships and rules implemented will be briefly described.

The dimensions of the main engine block sketch (Fig. 4 left) are directly related to the piston, connecting rod and crankshaft. The dimensions preceded by "fx:" have been obtained by means of an algebraic relation or equation.

In Fig. 4, the framed distance is the length from the crankshaft axis to the face of the piston head when at the top dead center position (9) and it is obtained by adding the lengths of the crank (7), connecting rod (8) and the distance from the pin to the piston head (Table 3).

$$(S/2) + (2 \cdot S) + (0.6 \cdot D) = 2.5 \cdot S + 0.6 \cdot D \qquad (9)$$

Figure 5 shows the parameters of a part and the dependencies implemented by means of the previous equations.

Figure 6 shows the engine configuration interface (left) and part of the source code of the rule (right) which, depending on the number of cylinders, defines the position of
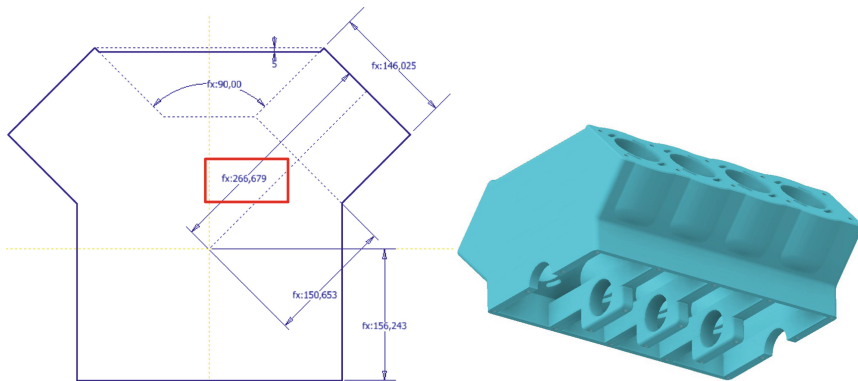

Fig. 4. 2D main sketch and full 3D model of the engine block.

Parameters	▽ Used by	Units/Type	Equation
— User parameters			
rel_cd	carr, diam	su	1 su
num_cil	cilin_u	su	8 su
mili	diam	m	1 m
diam	carr	mm	$(((4\,su * (cilin\_u\ /\ 1000000\,su) / (PI * rel\_cd))) ^{\wedge}$
cilin_u	diam	su	cilin_t / num_cil
cilin_t	cilin_u	su	4000 su
carr		mm	diam * rel_cd
ang		gr	90 gr
— Model parameters			

Fig. 5. Parameters of a part obtained by equations.

the connecting rods, inserts them and adds the bearing matching constraints. The result of its application can be seen in the Fig. 7.

Fig. 6. User interface and source code of a rule.

4   Results

Figure 8 shows the result of two different configurations: the geometry, size and number of parts, as well as the assembly, are generated automatically according to the values selected in the application interface (Fig. 6 left). In a few seconds, two different configurations are generated.

Thanks to the time reduction, different configurations can be compared immediately and the best option can be chosen. Figure 9 shows (by dynamic simulation with Autodesk Inventor), for an 8-cylinder engine, using the same crankshaft and the same average effective cylinder pressure, how the 90° configuration presents less vibration and achieves a higher rpm.
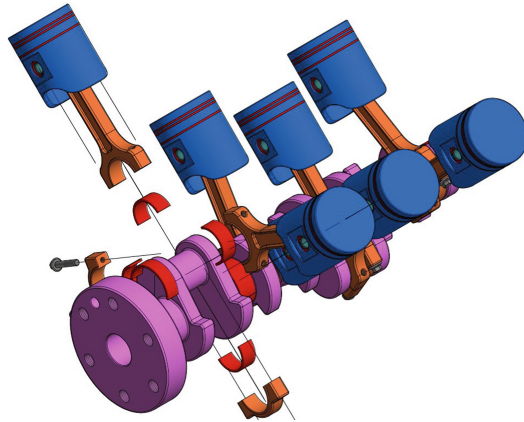
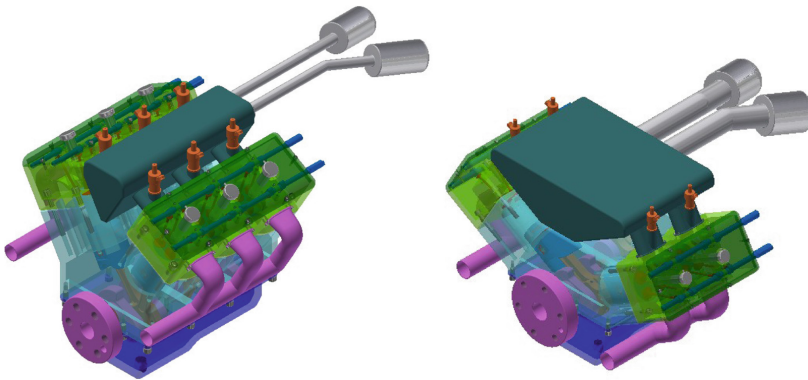**Fig. 7.** Generation, location and constraint of the first connecting rod with the rule of the Fig. 6.

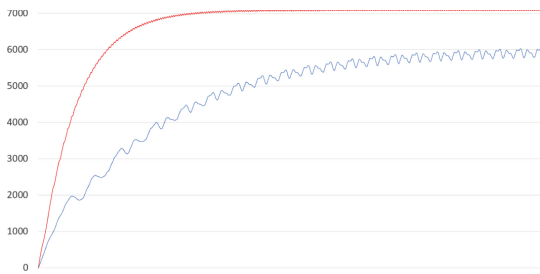**Fig. 8.** Two different V-engine configurations (6-cylinder at 30° and 4-cylinder at 90°).

Fig. 9. Speed evolution of an 8-cylinder V-cylinder engine at 90° (red) and at 60° (blue).

5   Conclusions

This paper presents a modeling strategy that, using constraints and rules, allows to automatically generating virtual models with different configurations in order to compare them and choose the optimal one. This strategy needs a previous deeper study, but it allows creating virtual prototypes in a more efficient way without the need of repeating the modeling and assembly tasks.

As an example, a virtual prototype of a V-cylinder engine has been developed, which allows different configurations by modifying the main parameters.

The work presented shows the viability of this strategy and its potential in the field of engineering education.

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