INCREASING SME SUPPLY CHAIN RESILIENCE IN THE FACE OF RAPIDLY CHANGING DEMAND WITH 3D MODEL VISUALISATION

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Abstract - Small and medium-sized machine-building enterprises (SMEs) have great potential for developing the relevant sector of the economy. For the sustainable development of such enterprises under the high pressure of technologies, it is worth choosing appropriate ways of presenting and exchanging information and using modern digital services following the concept of Industry 4.0. The analysis of the conditions of internal and external sustainable development of machine-building SMEs identified the main logistical problems limiting the growth of competitiveness. The article highlights the perspective of using digital integration of information about product life cycle: from CAD/CAE/CAM/CAPP design to supply and sales in conditions of horizontal cooperation. Particular attention had paid to determining the role of digital 3D models in Force Majeure circumstances, which are especially acute for SMEs. The research is based on using machine-building products - A Mixed Flow turbine. The digital transformation tool was the mobile application for the Android platform that made it possible to read a QR code and display a 3D product model with data. The proposed solution can increase the efficiency of supply chain planning due to constantly providing information about every stage of the product lifecycle.

Keywords: SCM; SME; 3D; Modelling; Data visualization; Virtual model; Lifecycle; Digitalization; Management; Industry 4.0; Sustainability.

1. Introduction

Small and medium-sized enterprises (SMEs) are crucial in the global economy. However, it should be noted that such enterprises have some barriers that limit their sustainable internal and external development. Such obstacles are mostly not inherent to large companies (factories): resource limitations, storage space limitations, complicated logistics, lower productivity and increased environmental impact. Such factors are the driving force for SMEs in the search for strategies to increase their competitiveness and stability in the market, especially since when the demand for products fluctuates, the stability of companies becomes variable. It is possible to avoid the consequences of such variability, for example, when integrating small enterprises between themselves to solve problems based on their initiative. [1] Among the existing solutions, the practice of using lean production tools to increase the sustainability of small companies and greening production is promising and timely - Lean-Green practice, [2,3], which is relevant for machine-building SMEs from the perspective of increasing the ecological efficiency of production processes. Lean-Green corresponds to the goals of sustainable environmental projects and aimed at reducing production waste and promoting the efficient use of energy resources in the production process. It should be noted, that environmental indicators are the central component of the sustainable development of SMEs. The European concept of the development of SMEs provides for the integration of information and digital technologies into their work [4-11], which is a direct factor in the implementation of lean production of SMEs within the framework of Lean-Green practices and is of crucial importance for the development of the enterprise and its economic growth. It is an important aspect given that in the era of globalization, SMEs must simultaneously ensure sustainable profitability through cost savings and be environmentally conscious. The need for developing modern enterprises in the key of frugal production requires searching for new solutions to ensure increased productivity, quality, and delivery by customer requirements by reducing waste and minimal use of resources [12]. That is why, to increase their competitiveness, domestic SMEs need to develop within the paradigm of lean production with the simultaneous introduction of digital services, as the driving force of the digital transformation of the modern economy, at all stages of the product life cycle, including in the implementation of supply chains, to improve the productivity of their operations, ensuring production flexibility in conditions of demand fluctuations and reducing delivery time. On the way to solving such significant technical and economic problems, the digitization of spatial information (3D modelling) about an industrial object at the stages of design (CAD)-engineering analysis (CAE)-preparation for production (CAPP)-production (CAM) of products can become the primary factor implementation of lean production using tools of augmented reality (Augmented Reality) and Lean-Green practices at domestic SMEs for their sustainable internal and external development. From the second point of view, it is digital 3D models that can become the basis for simplifying the integration of various SMEs to solve problems in conditions of sharp fluctuations in demand. That is, the participation of Digital 3D information in the chains of design-production, supply, sales and integration between enterprises can become one of the key ways to solve problems of logistics and sustainable internal and external development of SMEs.

According to the definition, 3D modelling is a computer graphics technique for creating a three-dimensional digital representation of any object or surface, which allows implementation of the technology of lean production, taking into account the features of internal logistics and external integration at the expense of cooperation of SMEs (Fig. 1), respectively to global standards of modern competitive production.

Flexible systems for the preparation and implementation of technological processes for the production of machine-building products in conditions of changing demand are highly complex and demanding in the management of product life cycle processes from design to supply and sale because, in modern conditions, they constantly work at very high speeds, where a slight stoppage can affect productivity, supply chain planning and costs for SMEs. That is why solid-state modelling in supply chains becomes not just a tool for presenting the visual characteristics of an object for the implementation of internal logistics when parts are manufactured but becomes the result of a generalized solution of using knowledge and technologies based on a 3D model for bringing a product to the market during the implementation of external integration of companies with to ensure their sustainable development (Fig. 1).

It should be noted that, on average, the costs of internal and external logistics, including the supply and sale of the product, make up about 30% of the product cost [13]. In logistics systems (especially for SMEs), the cost of distribution is usually the highest one-time cost, which is mostly more elevated than the cost of warehousing, equipment, and operating costs in general [14]. Procurement, production, distribution, warehousing, inventory, and information systems are essential logistics functions, among which distribution is a crucial function of the entire logistics system and a key link between manufacturers and customers in the supply chain faced by SMEs. In addition, distribution is the main factor of profitability in the company, as it has a straight impact on the cost of logistics and customer service [15] and, accordingly, on the enterprise's competitiveness level [16].

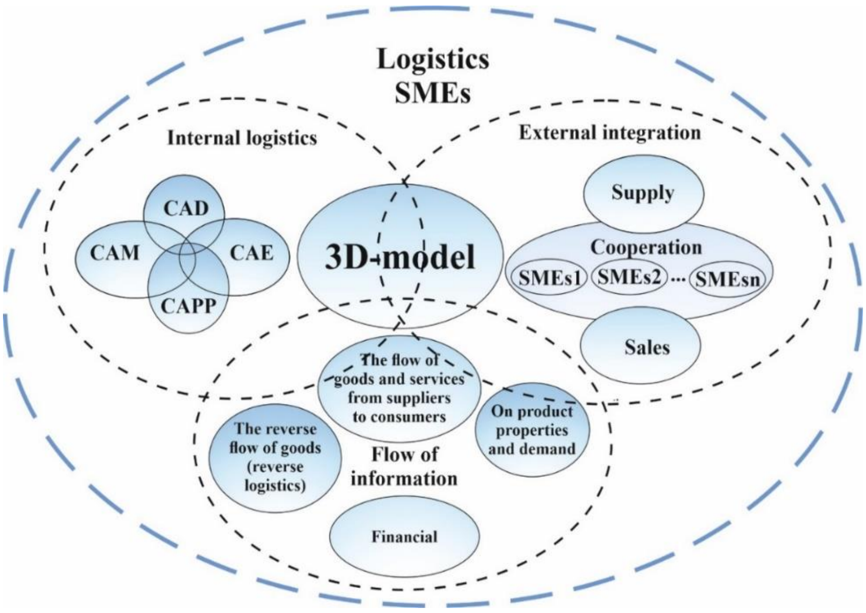

Figure 1: Benefits of 3D models in supply chains

Information technologies and telematics allow mathematical modellers to apply systems in real time. Developments in telecommunications and information technology have created many opportunities for increased integration of logistics functions, such as procurement of materials and distribution of products to customers [17,18]. Implementing principles of the "just in time" concept, enterprises face the problem of "how to balance regular and emergency shipments of necessary products, " which is an essential research topic [19,20]. What became especially relevant when solving the problem of finding ways to ensure the sustainability of the development of machine-building SMEs in conditions of sharp fluctuations in demand and supply by organizing and managing information flows about the product in supply chains.

2. Materials and Methods

An enterprise that met the above-mentioned criteria was selected for the experimental part.

Characteristics of the selected enterprise:

- Size: medium, year number of employees is about 249 (including all levels of employees).
- Type: production.
- The annual balance of the budget does not exceed 43 million euros per year.
- Manufacturing product: turbines.
- Location: Ukraine.

From the internal analysis and ways of internal and external sustainable development of SMEs, including conditions of Force Majeure circumstances, the main logistical problems faced by modern SMEs were determined and presented according to the descriptive method of SCM analysis in Table 1.

Table 1: Logistical problems of manufacturing SME and their brief description

Kind of problem	A logistical problem	Characteristics of the logistics problem
Internal problems	Limited resources	It is caused by difficult access to opportunities and resources, including a limited number of knowledgeable employees (10-249 total number of employees of SMEs) to solve problems in the area of finances, management practices to ensure effective logistics management.
	Limited storage space	Enterprise need to rent warehouse space due to limited own space. The growth of average rental rates for warehouse premises leads to the relocation of SME warehouses, and as a result, the restructuring of logistics connections.
	Difficulty in forecasting demand	That is because it is difficult for young companies to compete with monopolists in the industry. As a rule, small suppliers cause fear among customers, which leads to an unwillingness among potential distributors to take risks. As a result, SMEs may face problems of shortages or overstock, resulting in unpredictable market conditions, which is one of the main external challenges to the overall sustainability of the SME sector.
	Lack of economies of scale *	It is conditioned in advance by worse competitive conditions in the market, in which SMEs are by their very nature, against large enterprises. SMEs have higher production costs, which is associated with small series of production, lower level of scientific and technical potential, organization and insufficient qualification of personnel.
	Possession of logistic capacities	It is determined by the right of ownership of logistics facilities, as one of the key influences on the economic sustainability of the SME, which directly determines the efficiency of the SME.
	Limited transportation options	Due to the quick response of SMEs to changes in demand, which leads to the need to constantly establish new logistics connections and routes, because orientation to the type of end consumer (private or state, domestic or foreign) and general cost reduction should be the main principles for SMEs that have its role in supply chains. Thus, to ensure functional supply chains, a third-party provider of logistics services with a wide network, long-term partnerships and available resources is involved, the limitations of which are characteristic of domestic SMEs.

Table 1: The end

External problems	Complexity of supply chains	Due to the complexity of combining such aspects as procurement, product life cycle management, supply chain planning (including inventory planning and maintenance of current production lines), logistics (including transportation and management of transport capacities at the local and/or multinational level) with order management.
	Difficulty selling products	Due to weak marketing channels, insufficient advertising, misunderstanding of the "portrait of the ideal client", which leads to a lack of focus on effective channels (clients) for the distribution of existing resources.
	The complexity of horizontal integration	It is caused by the mistrust of small and medium-sized companies in potential subjects of cooperation and cooperation regarding the preservation of their autonomy (authenticity). This limits the ability of SMEs to adequately assess their capabilities and capacities that must be outsourced (including information, without fear of its turnover), which hinders the company's sustainable development.
	Stability in the conditions of Force Majeure circumstances	It is caused by the development of unforeseen external circumstances (todays situation on the territory of Ukraine), which do not depend on the actions and will of the parties to the agreement (blackout, forced full or partial relocation of the enterprise, loss of qualified personnel, disruption of logistical connections, etc.), but invariably leads to the impossibility of fulfilling contractual obligations.

*The effect of scale is the reaction of the average costs of the enterprise to the growth of the volume of its activity.

Logistics potential, from the point of view of supply chain management, can be defined as all economic, infrastructural, and technical means of any type, size, and structure available for an unlimited period, which is able effectively manipulated to achieve business success [21], and accordingly and development of SMEs. Consequently, promoting and implementing innovations from using Augmented Reality manufacturing tools in managing material and related information flow in the supply chains of machine-building SMEs is an essential development direction.

It should be noted that by optimising SMEs' preparatory, production, and logistics processes, all production-related losses can be eliminated. In contrast to the ideology laid before the development and promotion of the DIGICOR [22,23] platform, in the formation of supply chains with the horizontal integration (Table 1) of SMEs, the stability of sustainable development is predicted, which will be determined by the optimisation of production in conditions of variable demand.

The digitalisation of the product lifecycle could solve partial problems. The lifecycle, in this case, means all the information about the product, from the price and amount of material to the final product and stages of the manufacturing process. Such an information base will help to solve several problems, namely:

- limited resources linked with a lack of qualified employees,
- lack of economies scale due to transparency of all the processes, where could fund the bottlenecks,
- complexity of supply chains due to digitalisation of all material and non-material logistic flows,
- the flexibility to customer demands and visualisation of critical data can solve the difficulty of selling,
- the complexity of horizontal integration can be solved by digitalising logistic flows and better operative planning.

Digital information about lifecycle can give more information about products, their quality, the complexity of the manufacturing process and much more. The lifecycle can be divided into smaller steps, and the customer will have an opportunity to apply his requirements and see how it will affect the final product's quality and price. Digital data is much easier to translate into foreign languages and provides flexibility to customer needs due to the digital form of the lifecycle, which also can be used in the marketing company of the enterprise.

To increase the competitiveness of SMEs on the way to the creation of lean production through the Lean-Green practice and in the conditions of global digitalisation of preparatory, manufacturing processes, and other related activities (following the concept of Industry 4.0), the digital integration of information about a solid object promises production to manage the product life cycle at stages from CAD/CAE/CAM/CAPP to supply and sales in conditions of horizontal cooperation, the efficiency of supply chain planning, economic growth of production and sustainable internal and external development of small and medium-sized engineering companies as a whole. Lifecycle monitoring becomes especially relevant in the conditions of Force Majeure circumstances (Table 1), such as military actions on the territory of Ukraine, which significantly affected fluctuations in the supply and demand for machine-building products, both on a local/regional and global scale and led to the instability of both the internal logistics of the respective SMEs as well as the external component of its stable functioning.

Today's best-in-class supply chain strategies require demand-driven management models that can successfully combine people, processes, and technology with integrated capabilities to deliver goods and services with previously unattainable speed and accuracy, and in today's changing technological business environment, which is constantly evolving. Industry 4.0 supply chain management also has a significant advantage over traditional supply chain management, as Industry 4.0 ensures consistent planning and execution of production and support tasks while ensuring considerable cost savings to the enterprise. Also, it is possible to conclude about the feasibility of using the solid-state modelling methodology in the supply chains of machine-building products, which is especially appropriate for SMEs, where intelligent supply chain management systems will free up employees of small enterprises to perform other economically essential functions.

There is especially relevant to ensure the sustainability of SMEs forced to face Force Majeure circumstances (Fig. 2).

In unstable conditions, 3D modelling can become an advanced tool for ensuring the sustainability of a small or medium-sized enterprise in conditions of a sharp change in demand and supply by preserving information and its non-contradiction, which will allow for quick start-up (restart) of production of products by the current demand for re-lacquered production facilities. In addition, digital 3D models become the only tool in the conditions of the need for prompt exchange of relevant information between structural units of the enterprise, which may be territorially significantly separated.

2.1. Role of 3D Modeling in Supply Chain Management using the Example of Digitization of Individual Stages of the Mixed Flow Turbine Life Cycle

As already mentioned, for the sustainability of SMEs, they constantly need to respond to fluctuations in demand and supply in the market and use digital tools and solutions to ensure their competitiveness. The turbocharger is a crucial method to increase the engine's specific power and reduce the CO_2 emissions of piston engines, which is one of the priorities of the planet's sustainable development according to the United Nations [24] program within the framework of Lean-Green practices. At the moment, the question of increasing the efficiency of energy generating systems of Ukraine in the post-war period and their components, including Mixed Flow turbines, is promising. A feature of such turbines is the simultaneous presence of both axial and radial flow, and none of these flows is insignificant [25]. The principle of operation of mixed-type turbines is that the exhaust gas flow enters the turbine wheel not in a radial but in a semi-axial direction.

As a result, the turbine is a kind of "symbiosis" of radial and axial turbines. Therefore, the flow around the wheel is performed diagonally from below. The blades, accordingly, have a spatial curvature, due to which the outer diameter becomes unstable. That is why the high-quality execution of the turbine blade profile with the required curvature is a necessary condition for producing high-quality Mixed Flow turbines with high efficiency.

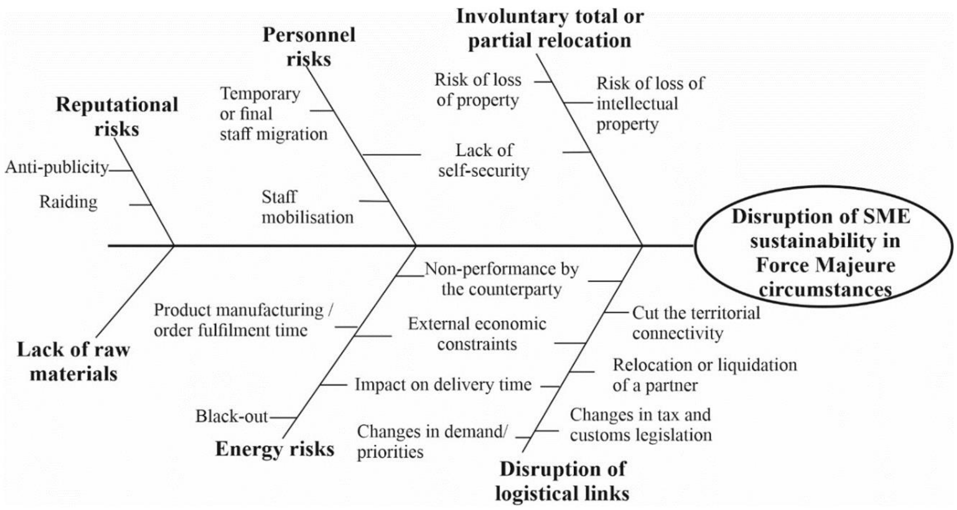

Figure 2: Ishikawa diagram of disruption of SMEs sustainability in Force Majeure circumstances

The three-dimensional presentation of the product design result will allow the implementation of the concept of lean production already at this stage of creating a supply chain in response to customer demand. The process of designing Mixed Flow turbines is quite complicated. SMEs' quick response to the current market situation can be provided by internal logistics, which will create prerequisites for their external cooperation, ensuring the sustainable development of the relevant machine-building company. The flexibility tool of internal logistics of the enterprise will be the high-precision 3D model of the product. The stage velocity diagram with flow velocity vectors and angles makes it possible to design the corresponding blade profiles to realise the inlet and outlet flow angles. In the next step, it is necessary to design the camber line on which the base profile will be superimposed. The camber line can build based on the input and output flow angles, taking into account the drop and deviation. It can be realised graphically or numerically.

A similar camber line is constructed using the Bezier polynomial. The general Bezier polynomial of degree n has the form:

$$B(t) = \sum_{i=0}^{n} (n\ i)(1-t)^{n-i} t^i P_i, \qquad (1)$$

where P_i is the points on the profile, t [0,1] is the curve parameter, and $B(t)$ is the position vector of the Bezier curve at the curve parameter t. A quadratic Bezier curve is quite suitable for building a camber line. For a conventional design of a turbine blade, it is worth to use:

$$B(t) = (1-t)^2 P_0 + 2(1-t)tP_1 + t^2 P_2 Q_t\ , \qquad (2)$$

According to the design conditions of the currently required turbine, equation (2) can be transformed to:

$$B_\xi(\xi) = (1-\xi)^2 P_{0_\xi} + 2(1-\xi)\xi P_{1_\xi} + +\xi^2 P_{2_\xi}\ B_\eta(\xi) = (1-\xi)^2 P_{0_\eta} + +2(1-\xi)\xi P_{1_\eta} + \xi^2 P_{2_\eta} \qquad (3)$$

Since the speed of rotation of such a turbine can reach up to 50,000 rpm, the probability of the formation of sonic flows is important in the design process, which becomes possible if the sonic Mach number is taken into account. Then the boundary conditions have the form:

for P_0: $\xi = 0$: $P_{0_\xi} = 0'\ P_{0_\eta} = 0'$

for , , (4)

$$P_{1_\xi} = \frac{1}{1+\frac{cot\Phi_{1c}}{cot\Phi_{2c}}}\ P_{1_\eta} = \frac{cot\Phi_{1c}}{1+\frac{cot\Phi_{1c}}{cot\Phi_{2c}}}$$

for P_2: $\xi = 1$: $P_{2_\xi} = 1'\ P_{2_\eta} = 0$

Using equations (3) and (4), we calculate the camber line coordinates by changing the dimensionless variable ξ from 0 to 1, with an interval of ξ = 0.01. In Fig. 3 shows the construction of the profile of the turbine blade for the rotor row using the angle of inclination, the distribution of the thickness of the actual profile, and the Bezier function [26,27].

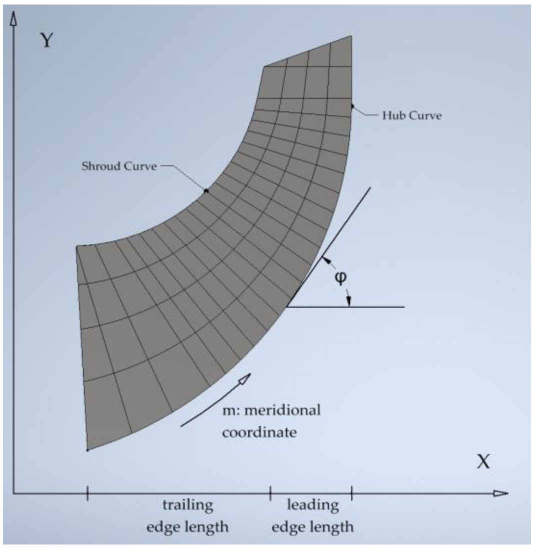

Figure 3: Mixed Flow turbine blade profile

The result of geometric transformations is obtaining a high-quality digital model of Mixed Flow turbines in the SolidWorks CAD system [25]. Thus, it can be concluded that the geometry of Mixed Flow turbines is a complex and complex task, and, accordingly, the creation of digital models of such a product requires the involvement of significant scientific potential and highly qualified technical personnel capable of, on the one hand, performing the role of system integrators and implementers of lean production tasks within Lean-Green practices, and on the other hand, to be able to solve related problems of mechanical engineering technology from the idea to the production of a product using digital services [28,29]. Elliot M. et al. [30] noted that, according to modern knowledge about Mixed Flow turbines, the natural advantages of the performance of such turbines are related to better compliance with the given geometric characteristics and not, for example, to improvements in their manufacturing technology. Thus, the role of 3D modelling in the life cycle of a Mixed Flow turbine, as a typical representative of a component of a responsible node, is justified by freed spatial thinking and the promotion of faster decision-making, freedom in the creation of complex geometric shapes and their digital analysis, reduction of time for the development of analogues, the greening of production, etc. Thus, a significant advantage of the 3D model of the object is the visual perception of the form by the subject (potential customer) to solve at least two important tasks: the task of displaying the visible result of the proposed object and the problem of reading digital information about the object of visualization, which is especially important for the sustainable development of SMEs within the Lean-Green practice.

However, solving visualization problems for SMEs is accompanied by a number of problems, which are illustrated in Fig. 4.

It should be recognized that despite the great prospects of using 3D models in modern supply chain technologies, the internal logistics of SMEs and their external integration through their cooperation still need to be improved and needs to find ways to solve such problems.

2.2. 3D Visualization of Information by Mobile Application about the Product-participant of the Supply Chain

There are many ERP programs (for example, SAP.ERP system [31]) that help to provide transparency of all manufacturing and non-manufacturing processes in the enterprise (internal logistics of the enterprise and partial external cooperation). The enterprise under study has no mobile version of the ERP program, which can provide on-hand information and display necessary data and a 3D model of the product. To give on-hand information to all the workers was decided to create a mobile application that will be integrated into the information system of the enterprise and ERP. Thus, the mobile application should achieve the efficiency of supply management directly "from places" while maintaining a high level of efficiency of the system as a whole [32].

The development of the mobile application opens up the opportunity to applicate the specific parameters of the product under study. According to Table 1, it can be expected that the mobile application will ensure the sustainability of SME and will be flexible to the current needs (whether you need to launch a new product or develop a new market segment according to sudden changes in demand and supply).

The proposed mobile application will be able to provide visual information about a supply chain participant object in "real-time" mode and will solve some accompanying problems to ensure the sustainability of SMEs:

- accumulation and provision of reliable data about a supply chain participant product; elimination of the "human factor" in extensive supply chains;
- the difficulty of balancing supply and demand;
- reduction of time for verification of the product-participant of the supply chain, etc.

Thus, a decision was made to substantiate and implement a digital application, including for smartphones, capable of visualizing a 3D model of a product-participant of the supply chain, which will allow machine-building SMEs to increase their capabilities to ensure their own sustainability in the conditions of rapidly changing risky demand and supply. For the demonstration prototype of the presented work (Mixed Flow-turbine), an application was developed on the UNITY 3D engine, which allows the rendering of 3D models on mobile devices. To recognize the QR-code*, the Vuforia plugin was used, which enables to receive data about the relative position of the marker, and thus provides the opportunity to place a 3D model of the product, a participant in the supply chain directly above it (Fig. 5).

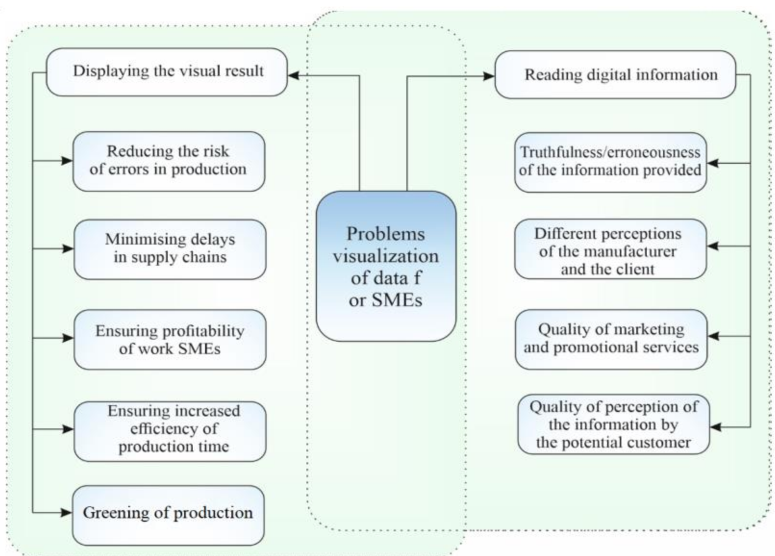

Figure 4: Data visualization challenges for SMEs

* QR - (Quick Response) codes are a type of barcode that be ably scanned with a smartphone camera for quick access to information

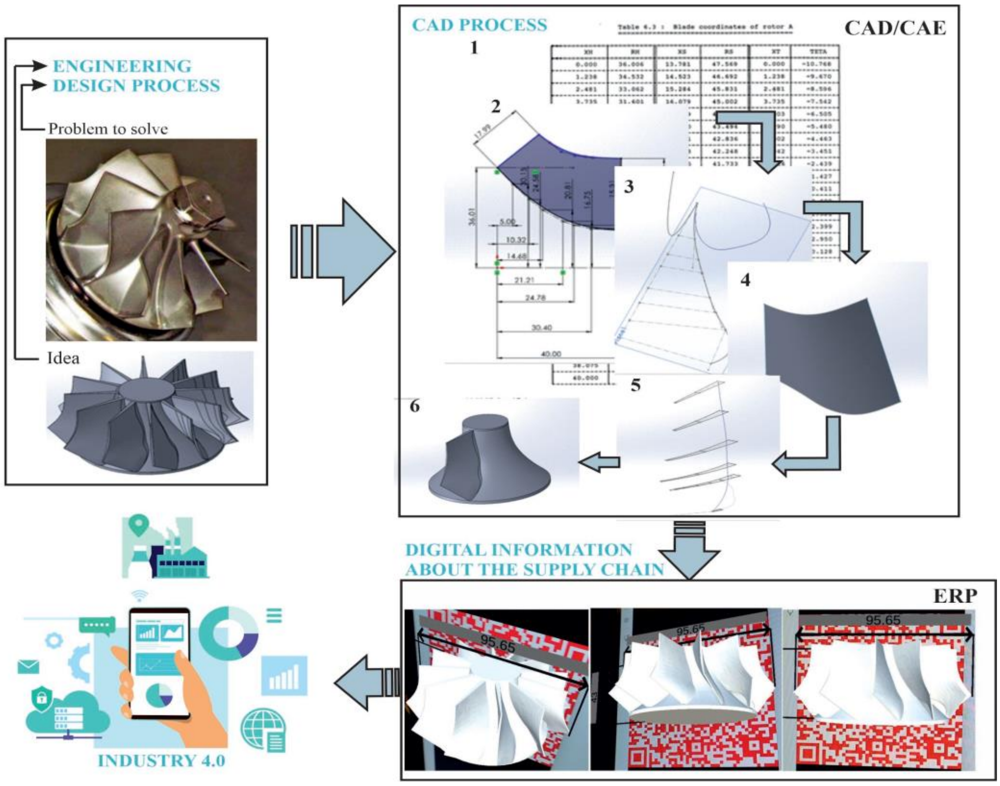

Figure 5: Proposed way of creating and displaying digital information about a supply chain product

Fig. 6 shows the algorithm of the principle of operation of the proposed application for 3D visualization of information about the product-participant of the supply chain.

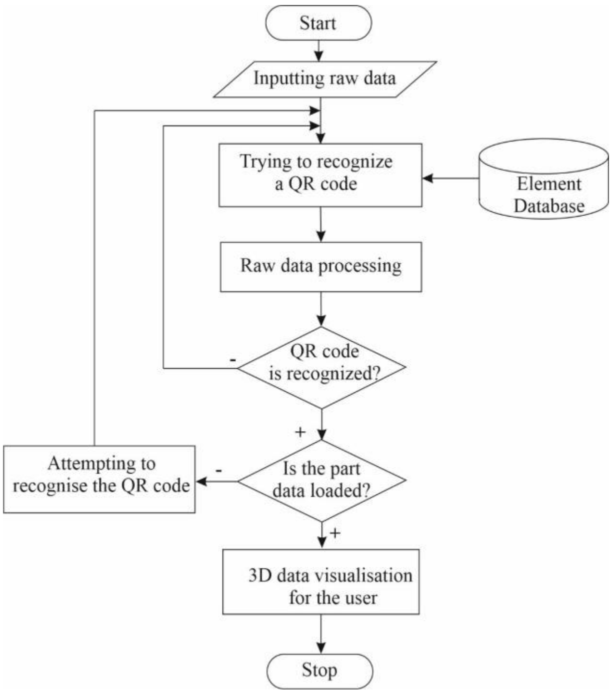

Figure 6: Block diagram of the supply chain product 3D visualization project

The working principle of which is as follows:

- the first step is to prepare the data for display and create the code;
- it is necessary to recognize the QR code containing the digital information of the object,
- then, the program will try to display the data associated with the marker,
- if the data has not been downloaded, the application will try to download the data from the server,
- visualization of the result for the user.

3. Results

The proposed way of creating and displaying digital information about a supply chain product there were proposed five steps of data conversion for mobile application. The proposed steps aim to adapt the model data so that the media can work and display the required data.

3.1. Data Conversion for Mobile Device

Since solid-state digital systems (CAD/CAE/CAM) work with vector formats, it was decided to convert the files into bitmap (.fbh) format. The reason for this was the need to simplify the drawing of digital models of supply chain components on mobile devices, as the computing power of phones is much weaker than a computer.

In the **first stage**, it is necessary to solve the problem of "simplification" of 3D digital models of objects - supply chains to increase productivity and reduce the memory consumption of the portable device (mobile phone), which will be extremely important for the user. Bldender [33], an open license program, and the publicly available anyconv website [34] were used to convert the files. The conversion was performed in automatic mode.

The **second stage** was to simplify the geometry of digital models of supply chain entities. This task was achieved both manually and automatically. It should be noted that manual simplification requires additional skills of a 3D artist and is labour-intensive. In addition, it is necessary to perform a number of iterations to reduce the number of artefacts associated with the simplification. However, taking into account the complexities described above, the manual method is still more flexible and allows for a more accurate result. The way of initial geometry modification allowed iterative modification of some polygons of the initial model until some condition was reached. For example, achievement of required number of polygons or achievement of required metrics for polygon areas.

The following operations have been highlighted in this method: vertex removal, edge collapse, vertex clustering, polygon removal, edge modification and vertex displacement. It is worth noting that the approaches have a drawback as there is no control over the normals of the resulting polygons, which significantly affects the resulting illumination. Also, to speed up the process of geometry simplification automatic simplification of geometry, such as Remeshing, was applied.

Block chain diagram (Fig.6.) describes the method, the essence of which is to create a geometry similar to the given part but with fewer polygons. To achieve this, it is not used to modify initial geometry, but to create vector fields, which are then used to generate new geometry of the digital model. This approach is applicable to reduce the complexity of 3D supply chain objects, but on low numbers of resulting polygons, they produce results with artefacts that require manual modification. Most often, these artefacts are related to the appearance of holes and self-intersecting geometry, which affects the quality of the digital model display. One way to overcome these problems is to apply neural network techniques where self-organising Kohonen maps are used to approximate the geometry [35].

The Level of Details (LoD) tool was used to optimise visualisation, solve the problem of big data, and display parts in screen space, both assembly drawings and individual assemblies. These Unity 3D geometry tools have the ability to generate detail levels for objects and scenes.

The purpose of this simplified geometry is to replace original polygons when they are far away from the camera during rendering and don't require a lot of detail, which becomes a set of sub-pixel triangles. Since the creation of a simplified geometry cannot be fully automated, there was decided to use a combinatorial way to simplify the models described above.

In the **third stage**, it was necessary to solve the problem of creating a marker to store information on algorithms for displaying digital models of objects participating in supply chains on a device. Since a QR code is a monochrome picture on which some devices (e.g. a smartphone with a special application) recognise text, it was chosen as the token to solve the problems of the work presented. As part of the SMEs' supply chain sustainability objectives, such a code would store the unique identifier of the part to be displayed or the information on where to download the part if it is not in the local memory of the device. A digital encoding method was used to store the data. The peculiarity of this method is that this type of coding requires 10 bits per 3 characters. The entire character sequence was split into groups of 3 digits, and each group (3-digit number) was converted into a 10-bit binary number and added to the already formed sequence of bits.

For example, in the context of a sudden market demand for a new modification of a turbo-compressor capable of reducing CO2 emissions, the relevant SMEs will be faced with the task of communicating the proposed technical solutions (production facilities) quickly and in a qualitative manner. The next challenge was to provide qualitative digital information about the participant in the supply chain being formed in time to ensure the sustainability of the small enterprise in the market. Let's assume that there is a unique turbocharger part number (Fig.5.) "1233778", which must be coded to further organize a sustainable supply chain. The part number was divided into numbers: 123, 377 and 8. Next, each number was converted into binary form: 0001111011, 101111001 and 1001000, and combined the result into one stream: 000111101101110111110011001000.

As the result of these actions, was got the sequence of the bytes, which are ready to be placed on the canvas of the future QR code of the article (Fig.7). The canvas consists of modules - elementary squares.

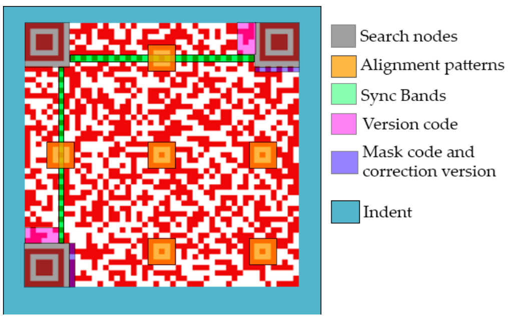

Figure 7: Placement of information about the supply chain entity on the QR code

Search patterns have been used to better stabilise the QR code in space relative to the camera. These patterns are a red square of 3 by 3 modules surrounded by a frame of white modules, which in turn is placed in a frame of red modules, which is also surrounded by a frame of white modules, but only on the sides where there is no indentation. Note that the search patterns are placed in the top and left corners (3 such patterns in total).

Alignment patterns were used to simplify the reading of content from the QR code. They have been used since version 2 of the QR code (that is, with the size of the QR code without the margins 25×25 pixels). They are a red square of size 1 by 1 module, which is surrounded by a frame of white modules, which in turn is again surrounded by a frame of red modules, and as a result, this pattern gets a size 5 by 5. The following condition was necessary while making the QR code: the aligning patterns and search patterns should not overlap. That is, when the version is bigger than 6 (in this case, the size of the QR code without the margins is 52×52 pixels), there should be no alignment patterns at the points (first, first), (first, last) and (last, first).

It should be noted that to track the QR code version, a description of the version code should be performed, making it possible for SMEs of the supply chain participants to optimise information about the digital models of the objects - participants in the supply chain. The version code is duplicated in 2 places and mirrored, specifying the module's colour in the coordinates (x, y). The same colour was used in the coordinates (y, x).

The **fourth step** was creating the marker with data. All remaining free space on the canvas was divided into columns: every 2 modules, no matter what is in these modules, except the vertical synchronization strip, which was simply skipped.

The filling started from the bottom right corner, going within the column from right to left, from bottom to top. If the current module is busy (such as a synchronization strip or alignment pattern), it was simply skipped. If the top of the bar is reached, the movement continues from the top right corner of the bar, which is to the left, and goes from top to bottom. Reaching the bottom, the movement continues from the bottom right corner of the column, which is located to the left, and goes upward. And so on, until all the free space is filled. This is where we store the unique part ID.

For marker identification were considered such plugins as ARKit, ARCore, Vuforia [35]. It was decided to choose Vuforia plugin because this plugin is relatively easy to use and, unlike other analogues, works on both platforms and Android and iOS (for example, ARKit works only on iOS), in addition Vuforia plugin is open.

When all the preparatory stages were done, it was decided to proceed to the final **fifth step**. At this point, it was trivial to add the models and QR code to the Unity project.

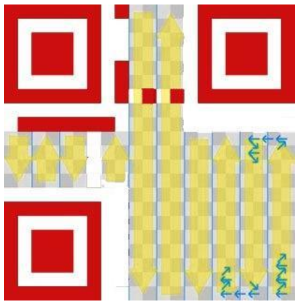

Figure 8: The process of adding data to the canvas to obtain a QR code

The Vuforia plugin was configured and was able to recognize the marker (Fig.9.).

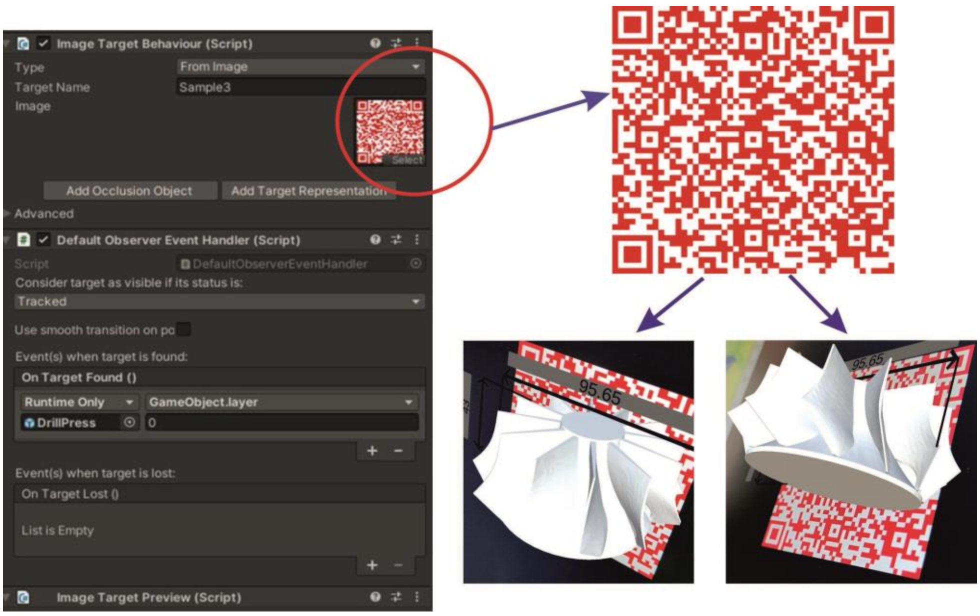

Figure 9: Setting up an augmented reality application using Vuforia on Unity 3D

If the marker was successfully recognized, the task of the plugin was to return point with relative rotation, position and scale to the camera. (Fig.9.).
The plugin was linked to the developed QR-codes with digital models of objects - participants of supply chains, which should be displayed when recognizing the code itself (Fig.9.).

Thus, the work substantiates that 3D visualization of information using modern services and opportunities in the context of the Industry 4.0 concept can be an economical and effective solution for small and medium-sized machine-building businesses, which will allow to improve their activities, ensure stability in conditions of rapidly changing demand, increase customer engagement and to optimize supply chains in the horizontal model of enterprise integration to increase their competitiveness.

4. Conclusions

In the conditions of developing digital technologies to ensure the sustainable development of SMEs, in recent years, there have been severe changes in the technologies of supply chains, the provision of internal logistics of enterprises, and their possible cooperation. However, the use of 3D models for solving such problems still needs to be improved. It can be explained by the fact that the role of the 3D model of the product is underestimated and is mainly associated with the solution of design-production problems (CAD/CAE/CAM/CAPP).

In the conditions of a sharp change in the demand for products, there is a need to develop new models for a new product. If such a product is multi-element, the presence of parts with the same characteristics increases significantly, which leads to the need to control and record visual information about the products to reduce the time for development and introduction to the market of competitive, in-demand products.

In addition, the digital visualization of the product in supply chains allows you to avoid errors related to the "human factor", purchasing the same components from different suppliers, protecting warehouses from excess products, increasing the environmental protection of the enterprise, etc.

In Force Majeure circumstances, 3D visualization allows you to optimize production by providing consistent information to structural units or partners to launch/relaunch products, using information about supply chain objects that can be used interchangeably and which can be used as spare parts in an emergency where they are challenging to get.

To ensure the sustainable development of SMEs within Lean-Green practices, a deeper understanding of the role of 3D models will reduce CO2 emissions and increase the environmental friendliness of production. Today's manufacturers of machine-building products have a massive amount of data presented in 3D models. Still, many do not use digital data to obtain information that can lead to positive changes in ensuring the sustainable development of the enterprise. Provided supply chain and logistics managers can gain insights from this data, the benefits to businesses will be substantial in the form of greater supply chain resilience, inventory consolidation, improved crisis management, and more environmentally conscious purchasing decisions. It was for the development of such an opportunity that the work presented a developed application that allows you to visualize digital data about the object - a product participant of the supply chain, and create prerequisites for the sustainable internal and external development of machine-building SMEs within the framework of Lean-Green practice., from solving problems assembly before selling the product on the market.
Further development of the proposed solution involves the creation of a server that will store all data about the set of supply chain objects (in terms of sizes, modifications, passport data, etc.) in the cloud and update the data about these objects in real-time

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