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CAX Software - The Next Level in Computer-Aided Technology

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ABSTRACT: Computer-aided has become more than just a necessity, but also a standard or demand in the standardization of processes, working methods, or design and manufacturing requirements.
Until now, IT programs were developed to help solve certain problems that are basically math problems. Now the complexity of IT programs has outweighed the complexity of the math problems that need to be solved, to enable the implementation of new methods and develop new ways for solving of hitherto non-existent requirements.
Many software has dedicated IT programming tools to expand initial software capabilities. But, connectivity pass beyond one software, to several. Interconnectivity in software development emerged. The current paper shows few practical applications of such IT methodology using Solidworks or other external software applied in robot's design.
KEYWORDS:CAX, computer-aided technology, robotics, Solidworks.

I. INTRODUCTION

Computer-aided technology contains at the beginning only focused small applications and computer-aided design (CAD) [1-5]. Soon after, when more complex mathematical problems begin to be solved using IT, a new branch emerges that allows the study of real processes in all their complexity. This new branch was named computer-aided engineering (CAE) [6-9].

Until now, the engineers were divided into two groups: design or manufacturing engineers. Today, manufacturing methodology required a close connection between these groups. The design engineers were involved in the fabrication process. Again, a new branch in IT appears. This branch is named computer-aided manufacturing (CAM).

Computer-Aided Manufacturing (CAM) is the use of software and computer-controlled machines to automate manufacturing processes of already designed and validated components in the virtual environment [10-12].

Computer-aided measurements or coordinate measuring machine (CMM) domain is another branch in IT. The initial CMM was developed by the Ferranti Company in Scotland during the 50s for a device for only two axes for checking of dimensional tolerances (D&T). The very first three-axis prototypes arrive during the 1960s and are invented by the Italian company DEA. Today, CMM technology evolves from haptic inspection systems to systems with non-contact, 3D scanning with optical and portable capabilities to expand quality assurance services, for recognition and 3D reconstruction in a virtual environment. This is actually a post-CMM Era [13].

However, the evolution of IT does not end here. The demands of Industry 5.0 and the Internet of Things (IoT) will certainly lead to even greater innovations, adding new branches for research, and new interesting chapters to the evolution history of Information Technology (IT) and Computer numerical control (CNC) [17].

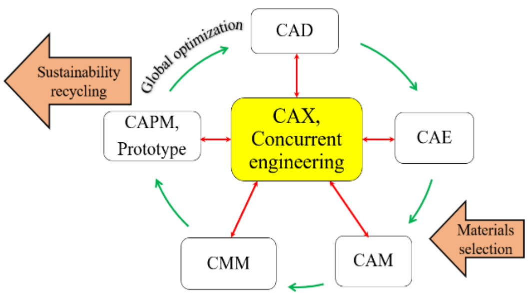

Fig.1. Complete design and manufacturing process

What is CAX? CAX is an assembly in IT of all previous presented computer-aided technologies, a suite of tools that use concurrent engineering to solve multi-objective design problems. (See Fig.1).

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CAX is a third-party software tool to extend functionality of main application. CAX is software with a concurrent engineering methodology implemented to allow various studies from different areas of the entire manufactory process and exchange information between them [14].
Moreover, by controlling the information distributed between all these departments, new standards have been imposed to:
- development of software for old and new design methods;
- documentation for manufacturing and assembling of parts;
- best selection of materials used and recycling specifications;
- information storage and learning methods for young engineers;
- involve more and more of AI technology in developing, creating and inventions.

Creativity will partially pass from human skills to machine skills.
Obviously, the CAX technology is only at the beginning, but it seems to grow faster than even imagine a few years ago.

Advantages of CAX technology:
- Reduce design time and product development costs;
- Ensuring quality standards and the emergence of new, more advanced standards and more adapted to new working methods;
- Maximizing process performance and IT proficiency;
- New methods for Product Data Management (PDM) and Product Lifecycle Management (PLM);
- Involved machine learning in design, manufacturing, PDM and PLM;
- Interconnectivity between different software and databases;
- World wide on internet connectivity and IoT;
- New learning techniques for engineers with advanced capabilities in 3D vision of design and results.

Disadvantages of CAX technology:
- Complexity in management of all product data need new skills for managers, engineers, and researchers from various domains of activity;
- Computer power in skills and learning will surpass human intelligence.

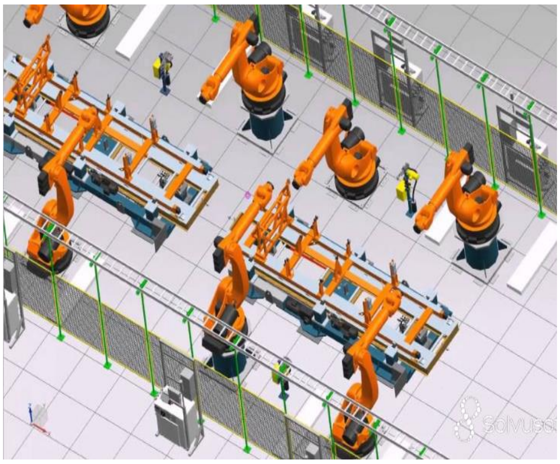

Fig. 2. Product Lifecycle Management using Siemens NX software [37]

All these engineering technologies are applied in a factory. The design process will be in direct connection with the manufactory, line design data, and process management of entire systems. This branch is named CAPM (Computer-Aided Production Management).

Figure 1 shows a complete process for design and manufacturing that includes all computer-aided technologies explained before. If the old design fashion was a sequential process (green color connections), the CAX technology is a parallel management process (red colour connections from figure 1).

Figure 2 shows a product lifecycle management process using Siemens NX software with capabilities to see in a virtual factory all real manufactory information. The control of all manufacturing operations is crucial in the industry, from product design and manufacturing process to client delivery and recycling activity. The correctness and completeness of regulation in manufacturing activities make the difference between meeting and missing customer requirements [15].

II. CASE STUDIES

The following cases cover many mechanical design activities, with applications focused on robot design.

2.1 Initial design: concept optimization

Any initial concept in design should start from new ideas and requirements. Requirements for a robot's design include required workspace for current activity, about weight, kinematic and dynamic performances, environmental requirements, strength, durability, and particular specifications (medical, corrosion, thermal, magnetic fields influence requirements, etc.).

The workspace is not easy to evaluate when the robot has many DOFs. A special tool for workspace evaluation needs to be developed through advanced knowledges of kinematics principle and programming tools.

Using detailed CAD model in Solidworks software and API programming routines, users can implement IT tools for a complete workspace evaluation based on geometrical parts constraints, robot position management and machine learning to avoid multiple task position and collision with others or self collide.

At this stage of the working flow the next chapters of the design project can be evaluated: workspaces, kinematic evaluation and optimization, singularities assessment or collision detection, etc.

Figure 3 shows ¾ workspace evaluation of a hexapod robot using Solidworks API.

Even at this early stage of the project the design can be study for optimization using evaluation of specific kinematic parameters to improve robot performances: dimensions and volume of the workspace, kinematic singularity locations, values in Jacobian matrix, robot dexterity, local conditional index, robot manipulability, global conditional index, etc. [16-17].

Because of the complexity of the geometry, also in this step is recommended to evaluate the self collision risk during movement into workspace [18-20]. The software selected should depend on the details of the geometry take into consideration. In case of movements in real scene, robot should have implemented routines for collision detection with objects that are evaluated in real time. Some geometry simplifications to reduce time for collision evaluation are mandatory (See fig 4).

2.2Structural assessment and optimization

Design evaluation for structural strength is most important criterion for safety management in using products during service life. Complex assembly in 3D involve complex load-cases, structural behavior and results to study based on many design criteria: displacements, stress, contact areas and pressure, friction and wear, thermal effects, non-linear behavior and damage, crack appearance and crack-front propagation.

A specific aspect in robotic design is efforts evaluation of robot in entire workspace in special in actuation system. Figure 5 shows two specific workspaces (efforts or speed workspace related to limits on actuators) for a surgical robot.

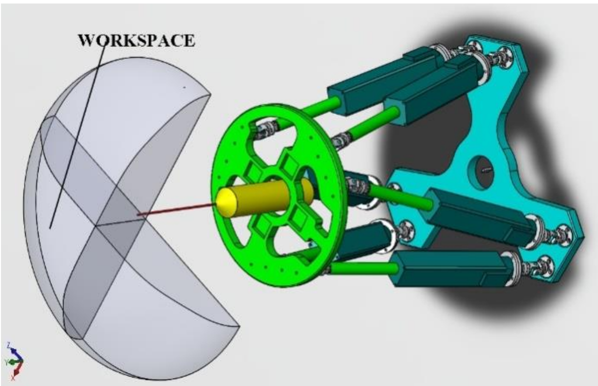

Fig. 3. Workspace evaluation in 3D based on Solidworks API

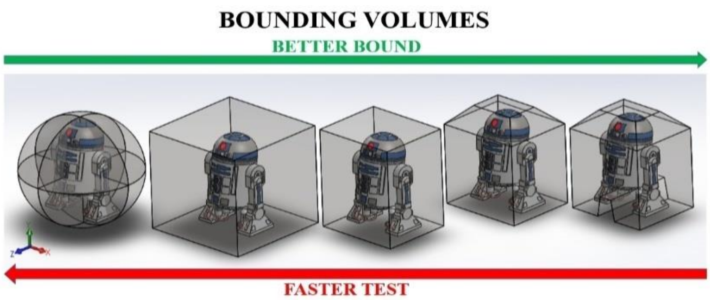

Fig. 4. Speed of collision detection techniques based on geometry details

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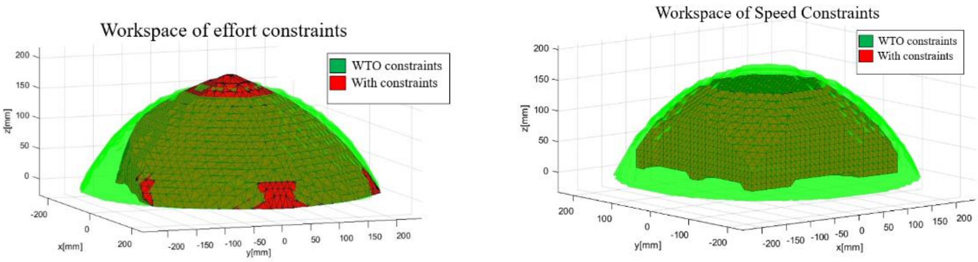

(a) Workspace of efforts (b) Workspace of speed

Fig. 5. Workspaces of hexapod robot using MATLAB

Durability has many aspects during of the strength assessment. Deformation in assemblies, stress level in components, service life of the products, crack appearance, crack propagations and components failure are only few. Evaluation of stress level in components during specific load cases is one of the most important. Starting from here can be done also optimization of parts or assemblies. In figure 6 can be viewed an optimization final results of platform shape using changes of topology in platform plane.

2.3 Dynamic behaviour assessment

Loads acting over assembly are not constant during mechanical task. Dynamic loadings have influence in structural behaviour by two major ways: structure response as reaction to eigenmodes and on the fatigue durability even when the amplitude is small. Resonance of structure at loading eigenvalues lead to rapidly appearance of damages.

Noise, vibration, and harshness (NVH) is a methodology for assessment of structural behaviour in vibrations, but not only. The eigenmodes and eigenvalues of a structure have a direct influence on the dynamic behaviour in service and vice-versa. Vibrations may occur at any dynamic loadings which may lead to the degradation systems involved.

The usefulness of knowing eigenvalues and eigenmodes for any structure is explained next:

1. Give information on the slenderness of the structure, i.e., the ratio between mass and rigidity;
2. Is important to know the fundamental frequency of a structure;
3. The system response evaluation to a transient load can be done by the modal methods;
4. Identification and correlation of models with experimental data [21];
5. Damage detection and localization [22-24];
6. Damping of structure in dynamic loadings depend also on parts geometry, material used and assembling particularities.

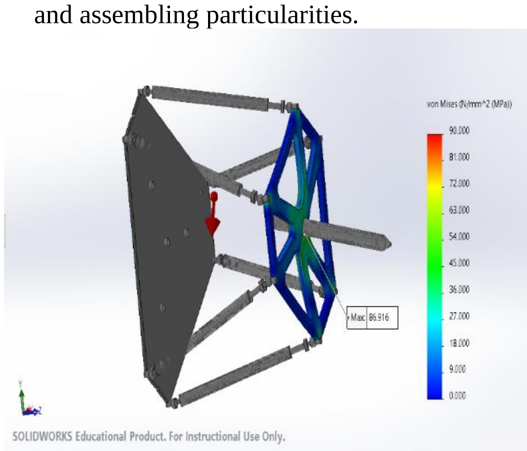

Fig. 6. Structural evaluation and optimization based on topology

2.4 Durability, service-life, damage detection, crack appearance, fatigue under crack growth

Durability of structure is evaluated today based on complex method. Durability assessment of structures has the next aspects:

1.Durability estimation under fatigue [25-26];
2.Damage detection and crack appearance;
3.Fatigue under crack growth.

The next presented case study shows service life estimation based on load cycle and S-N curve of material from database.

Theory of fatigue failure evolve to an advanced level of durability assessment by research of crack initiation and crack propagation. Plastic deformation is appeared when the mechanical stress is sufficient to permanently deform the material. Plastic deformation involves the breaking of a limited number of atomic bonds by the movement of atoms and create dislocations.

The life of a crack has two parts, initiation and propagation. At microscale level, dislocations play a major role in the fatigue crack initiation phase. It has been observed in laboratory testing that

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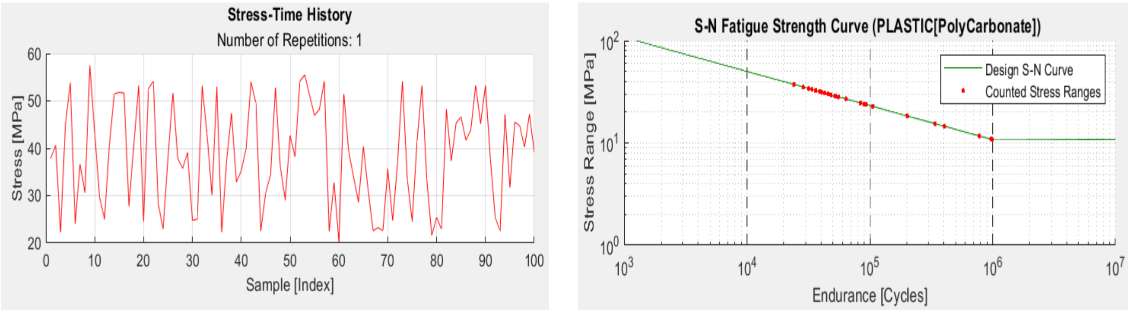
after a large number of loading cycles dislocations pile up and form structures called persistent slip bands (PSB) because of tendencies of atoms to move to a much lower stress levels and because dislocations have a preferred direction of travel within a grain of the material [27-28].

At macroscale level, the crack propagation depends on material, geometry, load case, stress level at crack front, and the position and dimension of the existent crack already initiated.



(a) Load history (b) SN curve and service life

Fig. 7. Strength durability estimation

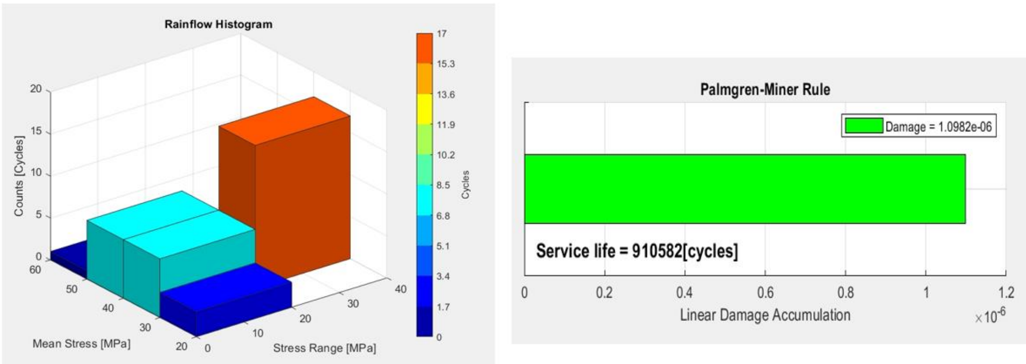


Fig. 8. Service life estimation – Rainflow analysis and total damage estimation

The next research case shows crack propagation analysis under complex fatigue load case in a complex 3D geometry. Crack is considered initiated at the areas with the maximum stress concentrator. Simulation was made with SIMMODELER software based on 3D geometry prepared in SOLIDWORKS.

After initiation, cracks are sized in the micro-scale domain. In many parts, is important to detect such cracks at this level, depend of the importance of these assemblies. This kind of detection is possible only with CT or ultrasonic scans.

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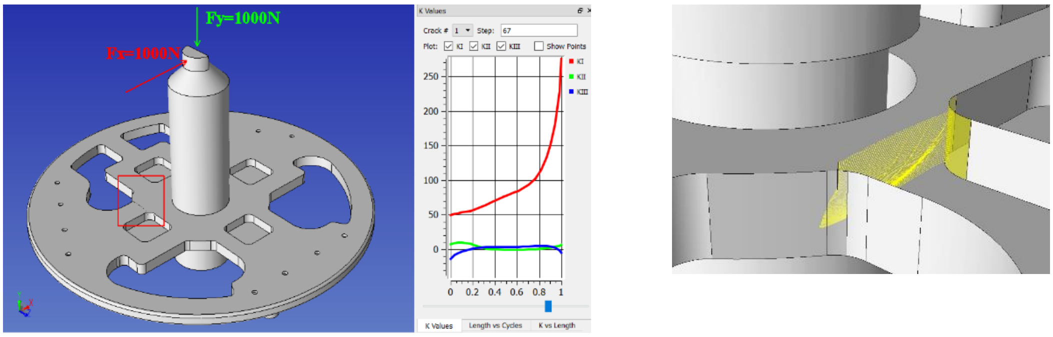
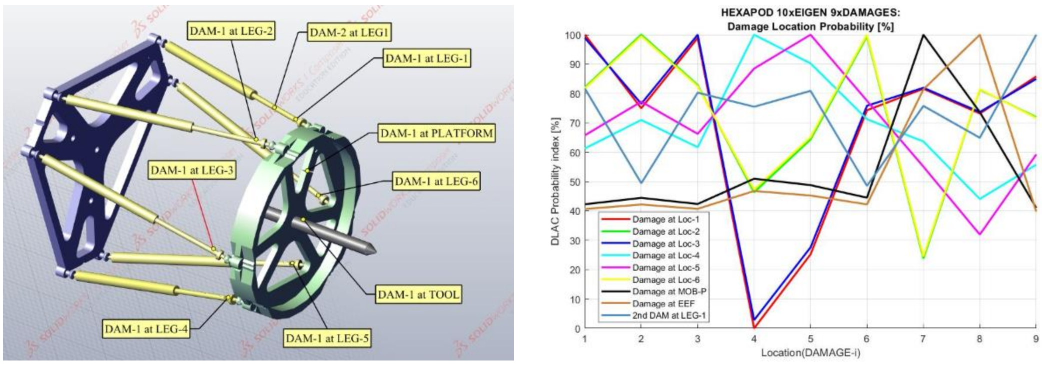


(a) K values during crack front (b) 3D crack propagation

Fig. 9. Crack appearance and propagation during failure



(a) Location of imposed damages (b) Probability index

Fig. 10. Damage detection and localization as probability index

In other assemblies, damages and crack grows until a macro-scale (visible) In these structures, the damages can be detected using SHM (System for Monitoring and Prediction of Cracks Development) techniques for monitoring during service of changes in structural behaviour. In the next research are presented some practical results for structural monitoring using an improved DLAC criterion presented in details in paper [29].

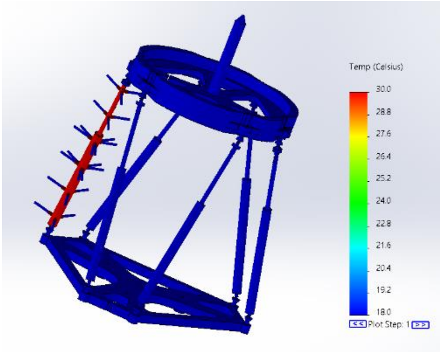
Many parameters from research should be evaluated as probability values because of variability and multitude factors that actually has influence over results.

2.5 Multiphysics evaluation of concept: thermal evaluation

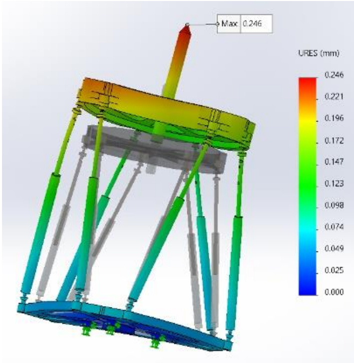
A robot will act in a real environment. There exist also environmental components that influence robot behaviour. Heat sources exist everywhere even inside of a robot structure. Malfunctions of a motor lead to overheating of areas and has influence over mechanical parts of the robot including precision in positioning, sensors result and measured values, linkages tolerances, wear and friction at parts in contact, mechanical behaviour of plastic materials used in construction, including risk for fire ignition and toxic air pollution etc.

Multiphysics evaluation of structures became a necessity in design, assessment, optimization, testing, and homologation.

The next presented case study shows thermomechanical evaluation based on assessments of thermal influence over mechanical parts of a robot. The thermal load considered was an increasing temperature of an actuator motor until 30 degrees when environmental temperature is 18 degrees. Deformation analysis shows a deviation at robot tool with 0.25 mm.



(a) Thermal field analysis



(b) Deformations due to thermal load

Fig. 11. Thermo-mechanical evaluation using SOLIDWORKS

2.6 Updating and correlation with test model

Complex assemblies in software for CAD-CAE simulations use some idealization techniques to comply the required task. Creating designs and prototypes with help on CAD-CAE software only, is not enough for better design. Evaluation of CAD-CAE software are made also based on real structure testing.

Real testing at specific load cases in quasistatic, dynamic, crash, and fatigue loadings should be required by design specifications. Many parameters will be study at experimental model for a good design evaluation:

1. Assessment of weight, eigenvalues and eigenmodes;
2. Deformation and stress level at specific load cases;
3. Damping and friction evaluation;
4. FRF and dynamic response measurement.

All these parameters will be compared with values obtained from CAD-CAE simulation. Real parameter measurements signals are over-imposed with noise and errors because of sensors precision and other environmental factors.

Correlation between all results and updating of CAD-CAE model is a common step in modern research and design. But many parameters in research studies should be evaluated in terms of probability. The real average probability of deformations that give good comparisons with the real model is around 90%, while for mechanical stress the value is 70%, and for the rest of the parameters (accelerations, forces, etc.) it drops even more. Dynamic behaviour of structures and friction in assemblies has also major impacts over the accuracy of the results.

2.7 Documentation deploy

Complex assemblies, complex load cases, complex structure behaviour, many parameters to evaluate, etc., lead to a huge amount of data for designers. All these aspects should be included in design documents. Many such documents could be made automatically today using CAX techniques.

Many designers for software already included such tools. But is not enough for all management aspects. Many additional common results or complex evaluation of results, documents or video presentations can be automatically generated using computer skills and in-site software or other IT tools.

2.8 Smart design, assembly builds

Existence of variability in parametric design is required today. Parametric parts and assemblies already exist in modern CAD software. Even more, scripting tools help engineers to built assemblies in a fashion completely automatically, prepare and manage simulations for internal or external solvers, extract results and prepare complex presentations that shows all concluding and final results.

But a smart engineer can go even more into the advanced levels of design. By developing tools researchers can discover completely new methods that using new parameters for design, new criteria for assessment, new shape for components, new ways for assembly, new ways for manufacturing and factory management, even new materials.

2.9 Path planning and control strategy

In the case of robot design, one of the most important issues in kinematics is path planning without exceeding workspaces (positions, speed, accelerations, loadings, etc.), avoid collision with forbidden areas, and free of singularity. Existing complex assemblies in 3D design led to many collision possibilities, many singularity locations, and many areas where actuators are near to their limits [30-31].

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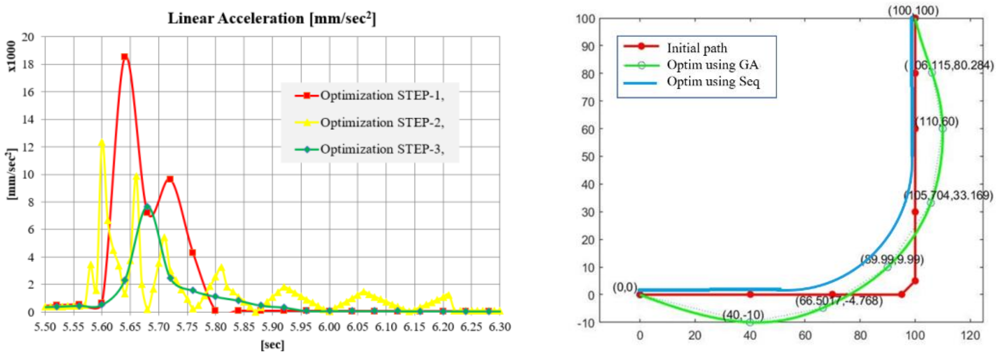
The next case study shows an optimization process of robotic trajectory and path planning strategy using two different methods: sequential classic method and GA (genetic algorithm). The objective function is the acceleration supported by robot during movements. The most delicate areas are those with small curvature at the same speed along the trajectory in space necessary to be performed.



(a) using sequential steps (b) using GA algorithm

Fig. 12. Path planning optimization

2.10 Sustainability concept

Production management and design to reducing cost for water, energy, waist materials are becoming a strategy for a modern factory. Corroborated with smart recycling strategy and process, it shows a modern view over future manufacturing processes.

Using more sustainable materials in product design, smart choice in using supplier's subassemblies are also important aspects for preparing modern manufacturing processes [32-33].

Sustainability has many aspects:

1. Economic aspects (responsible investments and business principles);
2. Environmental (recycling and environmentally adapted products and using better production methods);
3. Social (safe working environment and healthy).

2.11 Manufacturing management and smart factory

A design study should be correlated with all manufacturing tools that exist in factory. Impossibility to manufact a specific part by a specific procedure led to stop the entire design or manufacturing process.

Management of the manufacturing process shows the weak point and possibilities to optimize the process. Stock delays and process speed at each manufacturing phases has an important influence in mass production performances. Improvement in manufacturing timing could have influence over design phases and process also, even over materials used or ways to built a product.

2.12 Interconnectivity all the way

All these manufacturing aspects can be managed using a small number of software or even only one. Today tendencies in factory management are to concentrate of the evaluation processes using factory intranet connectivity. Design information's can also be exported and share to others.

World wide internet interconnectivity has a major influence also over educational aspects for entire humanity. Exchanges in information related to all aspects: educational, research interest, design methods, materials, manufacturing, recycling, will lead to a huge improvement in human interconnectivity [34].

2.13 AI, Machine learning and other assistive tools: computer vision and monitoring, real-time analysis, IoT sensors, IoT management

In several projects using computational (medicine, biology, IT and security, agriculture, etc.), artificial intelligence (AI) and machine learning (ML) has become as an important resource. But only few research tries to study the AI in mechanical design domain [35].

Using of AI and ML in mechanical design can be made based on many conceptual design criteria (company identity, logo, patterns, material selection, combination of methods – classic or hybrid, design level, strength assessment, durability, sustainability, etc.).

The next case study shows computer generated designs using AI and ML. Two different models that use different methods are presented.

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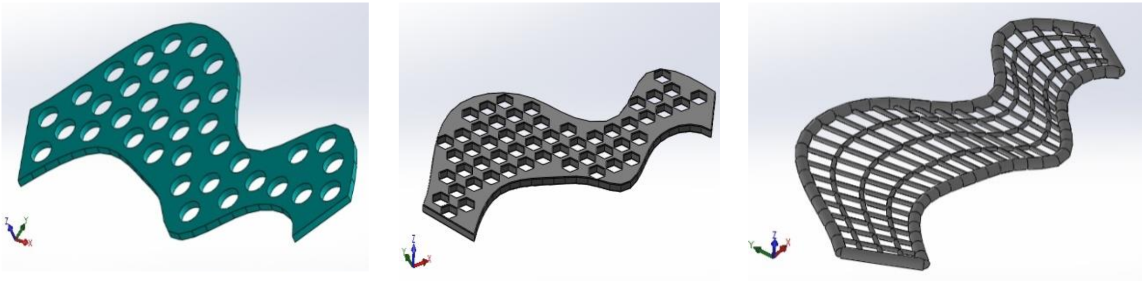
First method uses cutting material from initial raw material until fulfil all the requirements. The second method uses a combination of adding and cutting material until fulfil all the requirements.

Figures 13 shows the first model. Based on an imposed contour for design, was used AI and computer skills to develop structures that can fulfill requirements for strength and durability. Three types of results are presented.

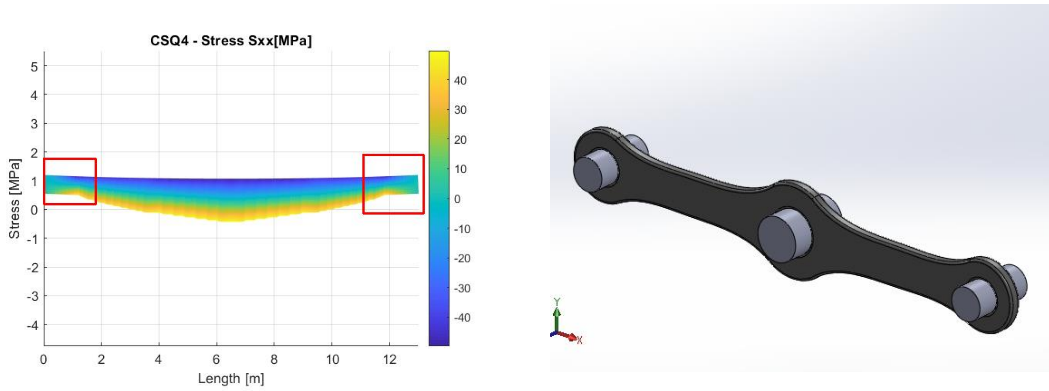


(a) Pattern with circles (b) Pattern with hexagons (c) Pattern with multiple constraints

Fig. 13. Mechanical designs using AI

Figures 14 shows the second model. Based on an initial raw material was used AI and computer skills to develop structures that can fulfill requirements for strength and durability. Two types of results are presented: examples for 2D plane model and 3D model. Load cases for models are simply supported at beam ends and with vertical force action on middle.

The AI principles reveal that for a real structure "Equal-Strength" shape is different then how we learn from the books – marked with red square in figure 14-a.
Using ML for some parts with specific dimensions for specific loadings, we can create applications that use NN (Neural network) techniques for new parts in mechanical design (figure 14-b).



(a) Cutting material (b) Modify shape

Fig. 14. Mechanical designs using AI

2.14 "Back to the future". Creativity as machine skills. AI current state.

ML and AI can help to create products based on client identity, needs and based on previous user experience, identify anomalies and finding errors in management or manufacturing process.
Is it worth it?

Even though machine learning is more accessible than ever in history, it still requires additional resources (developers and time) to be integrated into a product design and manufacturing. We must also think about whether the resulting impact justifies the amount of resources needed for implementation and if some ethical rules are violated by applying the studied methods [36].

III. CONCLUSION

Using AI and ML in mechanical design is not an easy task. Such technology required many

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computer skills and an advanced scientific background for researchers. In reality, AI is not 100% artificial. Maybe a better definition for AI is Augmented intelligence. The machines are far away from the moment when will do anything by themselves starting from zero, like all of us, humans.

But now the machines are just starting to learn.

CAD-CAE-CAM-CMM-CAPM is a complete cycle in production management using computer-aided technology.

CAX technology will become into the future more complex and even with many self decisional levels in industrial manufacturing management.

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