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Advanced Concurrent Engineering using CAD software-Classic, Avant-garde and AI

Ciprian Dragne
Department of Mechanics, Institute of Solid Mechanics of the Romanian Academy, Bucharest, România

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Corresponding Author: **Ciprian Dragne**

Abstract
Concurrent Engineering became a necessity in almost any domain of engineering activities from design to manufacturing because of all the requirements involved from multiple aspects studied and demands related to design, strength, quality, manufacturing, cost, service, measurements, monitoring, recycling, sustainability, etc.

The present paper proposes innovative methods for concurrent engineering in product design using advanced applications developed under professional CAD software SOLIDWORKS that can solve almost any aspects presented in the top list with an avant-garde methodology that involves classic approaches or innovative methods with AI.

Keywords: Concurrent, Design, CAX, SOLIDWORKS, AI

1. Introduction

Various specifications from service life and recycling management of the products demands also various requirements for concept, design and manufacturing. All requirements are connected at different levels and steps of design process. Most of the design steps are solved in sequential order. Only few are select-ed based on parallel decisions [1-3].

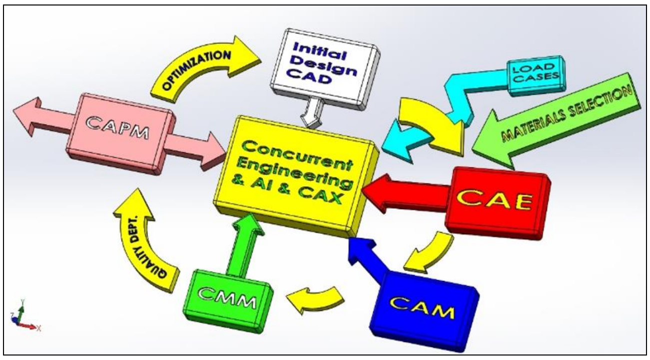


Fig 1: Complete manufacturing process

Concurrent engineering is a current requirement for modernization in all aspects of product manufacturing: Design, evaluation, prototyping, quality, production, optimization, production management, product recycling, production sustainability, intelligent recycling, etc. [4-6]. Fig 1 shows the complete cycle of manufacturing process. CAD-CAE-CAM-CMM-CAPM is a complete cycle in the production management process using inevitable and as-demand computer-aided technology. Computer-aided design (CAD), computer-aided engineering (CAE), computer-aided manufacturing (CAM), computer -aided measurements and quality (CMM), computer-aided production management (CAPM), are almost independent today in manufacturing processes.

Concurrent engineering aims to:

1. Centralization of information and decisions in an enterprise;
2. Access to all information's in all structures and at all levels;

3. The most complete access to data;
4. Increasing the speed of transmitting data in the system;
5. Storing information in a structured and standardized form;
6. Increase speed in making decisions;
7. Storing information for the future or for educational purposes;
8. The speed of information transmission anywhere in the world;
9. Transfer of information between partners, etc.

Moreover, by controlling the information distributed between all departments of the enterprise, new standards will be imposed to:

- Adapt the old methods to the new market requirements;
- Development of software for old and new design methods;
- New documentation for manufacturing and assembling of parts;
- The best selection of materials used and using new recycling specifications;
- New requirements for information storage;
- New learning methods for young engineers;
- Involve more and more of AI technology in developing, creating, and inventions [7].

The concurrent engineering totally changes the aspects related to decision-making, it leads to decision-making according to as many criteria as possible, according to more complete and all-encompassing criteria, the unitary presentation of all the aspects involved, the reduction of possible omissions and the re-duction of the minimization or omission of some problems that have arisen during manufacturing processes.

Concurrent engineering leads to the unification of evaluation criteria, as well as the combination of subordinate criteria, the emergence of completely new criteria, the use of modern methods of selecting performance criteria according to the weight of their importance in the final product, such as, for example, using AI methods in assessing the importance of the evaluation criteria.

Partially, all these aspects of concurrent engineering have been presented and specified by several authors, but what is missing is the practical side of the prob-lem, the development of applications that value all those aspects of CAX (Computer Aided Extended) collaboration.

What is CAX? CAX is an assembly in IT of all previous presented computer-aided technologies, a suite of IT tools that use concurrent engineering to solve multi-objective design and manufacturing problems. The old design fashion style is still in a sequential process, but the CAX technology is a parallel management process (See Fig 1) [8].

The CAX tools are at this moment State-of-Art.

The lack of collaboration or insufficient collaboration between IT and engineering departments today makes the full implementation of concurrent engineering applications not being effective and practical.

Concurrent engineering applications require knowledge from all the branches involved: Engineering, manufacturing, acquisitions, and sales, plus advanced knowledge of such techniques if AI methods are also involved. The number of such specialists is very small at the present time for advanced research of such techniques, specialists capable of managing all these aspects, that is why this lack of communication is observed in practice [9].

A new technological leap is on the horizon: Artificial intelligence.

The first steps have already been taken now. The development of intelligent systems is already a reality. The management of systems in everyday life has led to the development of products that interact more intelligently, to the develop-ment of robots that have gained the power to understand the environment on their own and learn from this interaction, to communicate as closely as possible in the human's language, to make the right decisions, etc. After many human dreams throughout history to create something that can be life-like, autonomous robots are already a reality [10-11].

Creativity will partially pass from human skills to machine skills.

The development of CAX applications will also be boosted by production systems that need to be adapted to increasingly restrictive sustainability criteria.AI could boost communication between various departments or accelerate the development of specific applications [12].

The sustainability criteria, the creation of environmentally friendly products, and the most complete and correct recycling of materials will also lead to the emergence of specialized departments. The system for the most efficient use of materials, material scraps, and waste parts, must become a separate department in the future through the development of intelligent material recycling centers.

2. Methodology

The present paper proposes an innovative application that uses the CAD soft-ware for complete CAX management, but not only. Inside the IT tools can be implemented easily many users' new criteria for assessment or optimization. The Fig 2 shows the GUI interface of the application that use SOLIDWORKS API for management of concurrent engineering methods. The CAD assembly pro-posed for testing is a hexapod robot but not only.

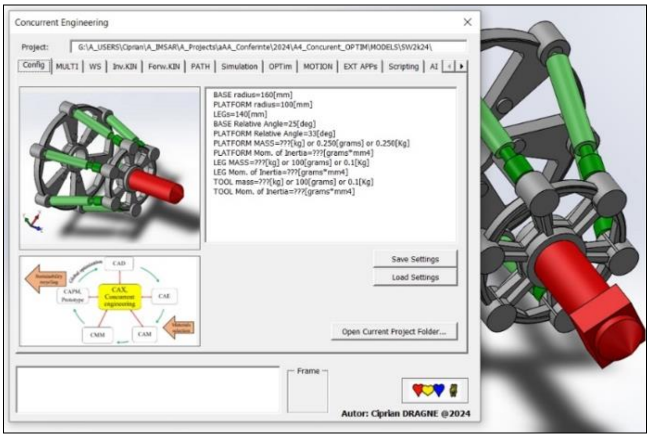


Fig 2: GUI of an innovative application for Concurrent Engineering

There are many types of methods implemented for assessment of the design:

1. Workspace and kinematics of the robotic system;
2. Specific connectivity with external software for rapid evaluation;
3. Path planning movement and motion study;
4. Simulation and optimization using different criteria simultaneously;
5. Scripting capabilities for complex studies;
6. AI methods implementation for optimization and cross-over assessment;
7. ARDUINO connectivity with real model or sensor systems;
8. Plug-ins with various external applications for CAD, CAE, or CAM;
9. Specific platform for user definition of design variables or optimization objectives;
10. Specific platform for animations of the current CAD model;
11. Bases in implementation of the natural language in engineering
12. Multi-commands capabilities.

2.1 Procedure using forward and Inverse Kinematics

As we know, the Forward Kinematics of a parallel robot is an iterative procedure. This method is time consuming depend on required errors for methodology, and is slow when robot has many actuators [13]. The next method for Forward Kinematics assessment is very quick and use geometrical constraints of CAD model. The methodology precision is very high and depend on CAD software used and internal setting on it. The GUI (graphic user interface) of the SOLIDWORKS API software subroutine for forward kinematics is presented in Fig 3.

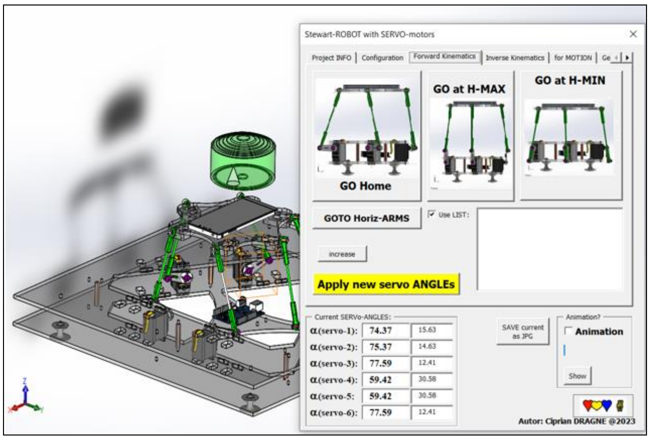


Fig 3: GUI of SOLIDWORKS for Inverse and Forward Kinematics

The main advantage of the method is that involve in Forward and Inverse Kinematics only one step to solve the problem of robot pose.

2.2 Simulation subroutines

Simulation section allow commands to run and control FEA solver with various simulation types and parameters with internal (in SW) or external soft-ware. Fig 4 shows the GUI of this section.

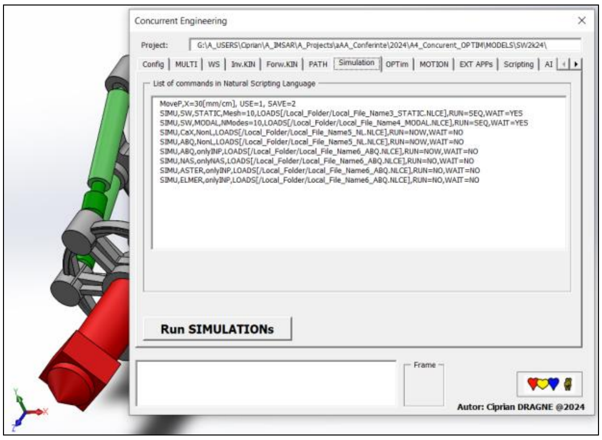


Fig 4: GUI of SOLIDWORKS plug-in for Simulation

The simulation section can even run different solvers in serial or parallel execution sequence.

2.3 Optimization subroutines

Optimization subroutines allow to define many types of user objective functions and variable parameters for optimization. Fig 5 shows specific GUI and a few examples of commands to execute subroutines for optimization. Results can be independent or interconnected for an overall optimum final result.

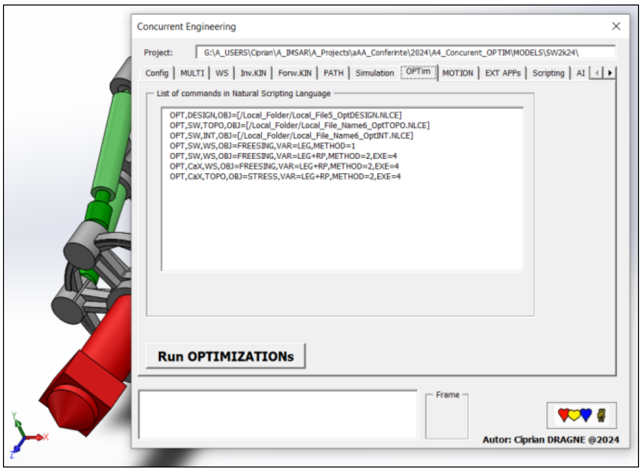


Fig 5: GUI of SOLIDWORKS plug-in for Optimization

Optimization strategy can involve various types of solvers, from internal in SW or external applications and even AI strategies.

2.4 External applications

External applications can be used for specific type of mathematical form to solve various types of equations in:

1. MATLAB
2. User-defined executable software (compiled sources)
3. User-defined subroutines in C++
4. User-defined subroutines in PYTHON.

Fig 6 shows a list with few external applications used by the author. An ex-tensive example is presented at Chapter 3 as research study.

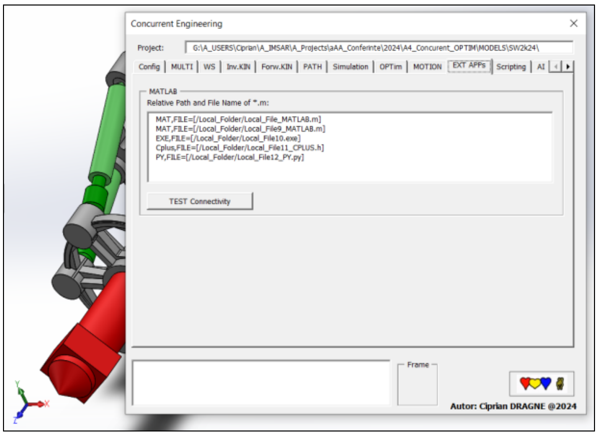


Fig 6: GUI of SOLIDWORKS plug-in for External Applications

External application could be any MATLAB function defined by user or by others, any software subroutines defined in C++, PYTHON or already compiled if has in input or output variables a clear meaning for SW plug-in user.

2.5 AI involved in Concurrent Engineering strategies

There are many AI strategies implemented in WWW and research papers but very few are connected with Engineering field of design [14-16]. Fig 7 shows a list with AI strategies implemented inside of this SW plug-in.

AI strategies refer to particular design stages that can use internal subroutines or external applications:

1. SW – internal 2D or 3D
2. MATLAB - external
3. CalculiX for 3D optimization
4. Interlaced AI strategy for multiple solvers.

Again, any other type of solver can be involved in AI strategy defined by user.

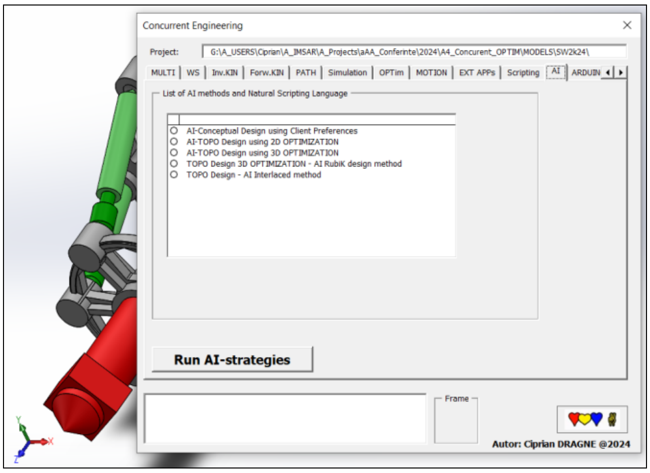


Fig 7: GUI of SOLIDWORKS plug-in for AI strategies

A specific example that uses AI strategy are presented at Case Studies chapter.

2.6 ARDUINO Connectivity

To test experimental models that use ARDUINO, the SW plug-in has capabilities to send specific commands for movement of a real robot according to internal variables defined.

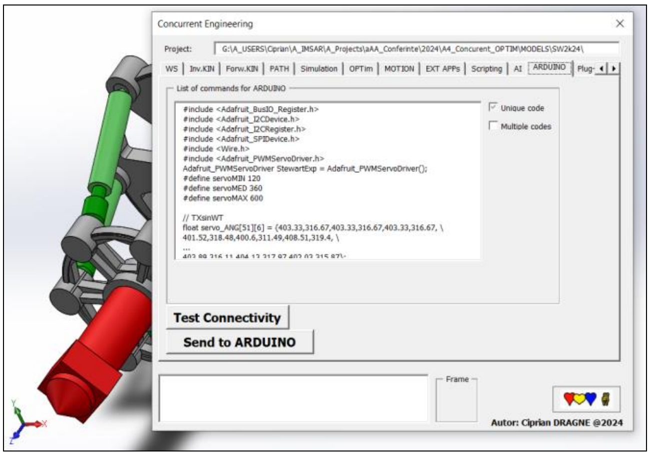


Fig 8: GUI of SOLIDWORKS plug-in for connectivity with ARDUINO

Implemented code can be defined in a unique C++ ARDUNO code, in a specific list of code sequence or in Natural Language defined inside the SW-plug-in for a quick and clear asset.

2.7 Plug-ins of the Concurrent Engineering SW-plug-in

Inside of SW-plug-in for Concurrent Engineering was also defined connectivity with its own plug-ins for a clear definition of GUI. Fig 9 shows a list with already defined plug-ins of this SW application for Concurrent Engineering.

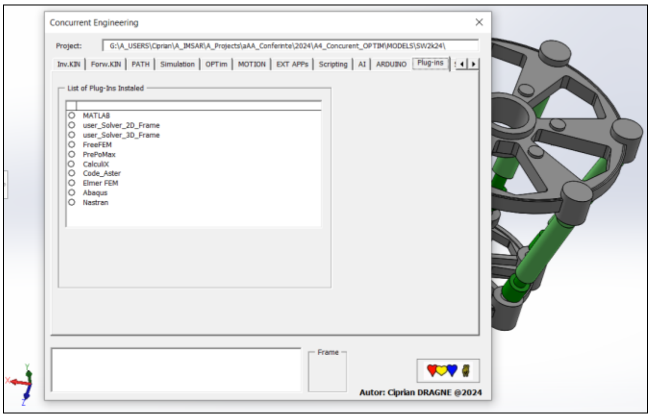


Fig 9: GUI of implemented additional plug-ins

Internal plug-ins should be defined and installed in specific form of SW application.

3. Case Studies

For assessment of the Concurrent Engineering Application was selected the next case studies:

1. Topological optimization of Hexapod Robot platform inside SW;
2. Topological optimization of a simple supported 2D beam using external application and AI strategy;
3. Topological optimization using external application and AI strategy using 3D FEA model.

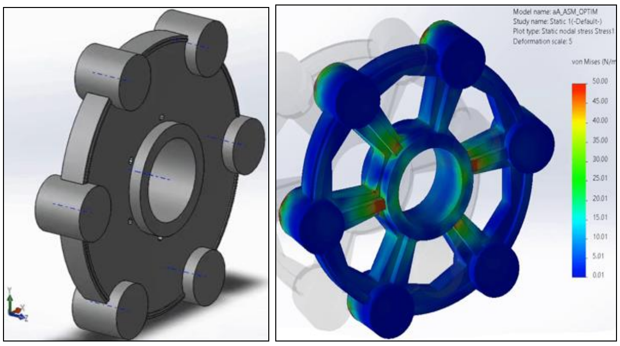
Optimization of a robot design

The first case is a topological optimization case study based on three objective functions:

1. Reducing weight;
2. Strength objective 50 MPa for 3 different Load cases

with 1000 N applied at tool;

3. Fundamental frequency of the robot assembly at minimum 60Hz in the pose at home position.



(a) Initial design (b) Final design

Fig 10: Topologic optimization using SW-plug-in

Material used for the platform, base and tool of the robot is ABS. The actuators are made from stainless steel AISI 304.
This design aimed to create a robot used in medical applications. The complete task and requirements were implemented in studies according to many papers from the literature review that imply the requirements for workspace, kinematic performances, strength, materials selection, manufacturing, etc., in assessment and optimization methods, using classical or AI strategies involved [17-21].

Topologic Optimization of 2D beam using AI
The first case is a research study for beam design optimization for equal strength optimization requirement.

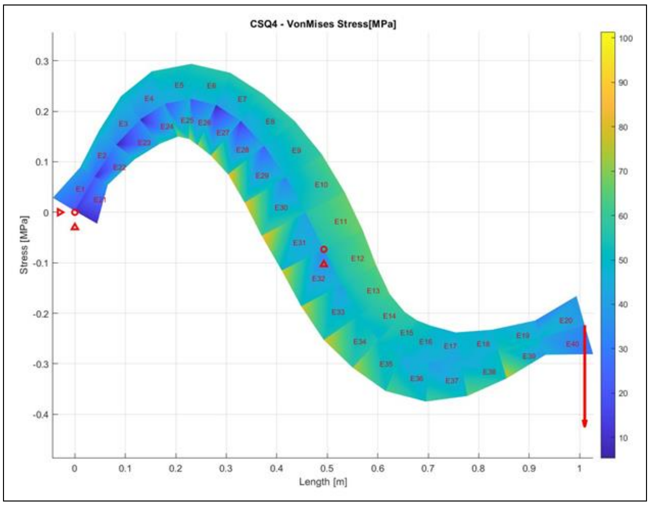
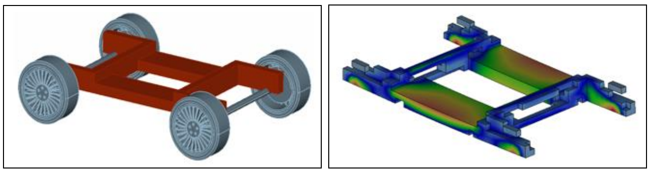


Fig 11: Topologic optimization using AI

The use of AI and machine learning in computer vision shows promising, even astounding, results. The anomaly at the ends of the beam it can be explained by the next sentence:" at the locations where we have boundary conditions or loads, should have more material".

Topologic Optimization of 3D assembly using AI
Multi-criteria topological optimization with AI involvement for multiple computational cases are presented here. The results for research study of topologic optimization for specific assembly (SUV car body) under simultaneously 20 load cases are presented in Fig 12.



(a) Initial design (b) Final design

Fig 12: Topologic optimization in 3D using AI

For this research was used the next 20 load cases:
1. Longitudinal torsional rigidity (min 20000 Nm/deg +/-);
2. Local axle stiffness (min 1500 Nm/deg + or -);
3. Longitudinal stiffness (min. 40000 Nm/deg + or -);
4. Lateral stiffness (30000 Nm/deg + or -);
5. Vertical static (gravity, engine, passengers, tank, luggage, other concentrated masses);
6. Vertical dynamic (1.5 g - inertial loads);
7. Running in a curve (V=100 km/h, R=300m, left-right, inertial loads);
8. Fundamental frequency of vibration mode (min. 30 Hz - bending, modal analysis);
9. Side collision (64 km/h, static loads applied left-right);
10. Emergency braking (3g - inertial loads);
11. Acceleration (2g - inertial loads);
12. Longitudinal impact forces (64 km/h, forces applied centered or left-right).

The optimization strategy implemented for this case is presented in Table 1.

Table 1: Optimization strategy implemented for research study no.3

Global step	Optimization strategy	AI	Obs.
1	Each calculation case is partitioned into sequences	NO	-
2	Each sequence has a search error of 10% of the criterion value	NO	-
3	Each calculation case is double-checked at each sequence	YES	Pre-test sequence
4	CNN (convolution neural network) selects where to remove or add material	YES	New model
5	The cycle continues until all sequences are evaluated	NO	-

This innovative method for AI was named RUBIK-AI Optimization Strategy

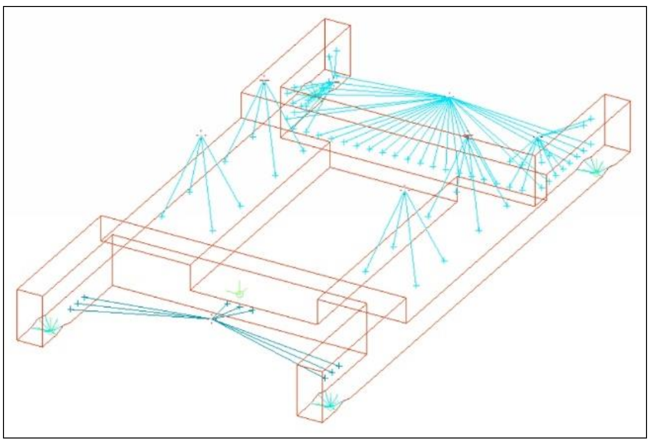


Fig 13: Complete FEM for simulations

A complete FEM for simulation is presented in Fig 13, where are included the gravity, engine, passengers, fuel tank, luggage, or other concentrated masses.

4. Conclusions

In this SW-plug-in was implemented many methods. Most are classical. Few are innovative in using Concurrent Engineering strategies for sequential and parallel assessment, for using AI strategies involved or not, for connectivity with many internal or external solvers, for connectivity with experimental model, for scripting language developed inside, etc. [22].

Future work will aim an implementation for real-time robot path monitoring and correction of the trajectories, based on information from multiple type of sensors and using metrological feedback from a laser system for measurements. Additional methods for optimization of the sensor locations, and monitoring of the robot health assessment will be implemented into our application.

AI techniques could be a good partner for methods used in mechanical design. Machine learning and AI could help a lot in a complex system assessment procedure. Continuously research will reveal new innovative methods for engineers. Further research will involve other assessment studies for AI in mechanical fields. Using AI leads to the fastest technique in optimization.

I'm training my computer to give me the best answers!

Specific conclusions for research case no.3:

1. Sometimes, too many load cases could give results hard to understand relative to specific load cases and design details. The methodology shows good results for global concept design;
2. Details in design should involve local details in parts assembled (specific fasteners, specific parts for connectivity, etc.);
3. Boundary conditions, locations of applied forces, or additional masses influence the AI-RUBIK results;
4. Load-cases order has influence over the final design;
5. AI could also be used in load case usage order selection but are needed more pre-testing;

AI should also be evaluated ethically. The unrestricted use of AI applications in the control of weapons and techniques of war can have catastrophic effects over entire world. The manipulation of information in www, press and television for the purpose of obtaining advantages will create many problems for the harmonious development of humanity [23].

Because of limited space for paper presentation, are shown here the results only for few studies. Many other cases should be included for a better understanding and assessment of the methods and the entire capabilities of this SW-plug-in for Concurrent Engineering.

Further research will include:

1. Study for influence of the load cases order in the final design;
2. Apply methods for other designs;
3. Develop of the RUBIK-AI for design of the local areas;

The complete task of the simulations was developed based on MATLAB soft-ware [24], SOLIDWORKS Educational [25] and user defined programming routines [26].

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6. References

1. Turino J. Managing concurrent engineering: Buying time to market: A definitive guide to improved competitiveness in electronics design and manufacturing, 1992.
2. Han KT. A Study on the Die Shape Machining using CAD/CAE/CAM System. Journal of the Korean Society of Manufacturing Technology Engineers. 2022; 31(2):86-93.
3. Kyratsis P, Kakoulis K, Markopoulos AP. Advances in CAD/CAM/CAE Technologies. Machines. 2020; 8(1):13.
4. Shina SG. ed. Successful implementation of concurrent engineering products and processes. John Wiley & Sons, 1993.
5. Ryalat M, ElMoaqet H, AlFaouri M. Design of a smart factory based on cyber-physical systems and Internet of things towards Industry 4.0. Applied Sciences. 2023; 13(4):2156.
6. Yi Ki, Jeong Young-Sik. Smart factory: Security issues, challenges, and solutions. Journal of Ambient Intelligence and Humanized Computing. 2021; 13. Doi: 10.1007/s12652-021-03457-6.
7. Sajad Sm, Son Yoo Ho, Noh Sang Do. A Conceptual Definition and Future Directions of Urban Smart Factory for Sustainable Manufacturing. Sustainability. 2022; 14:1221. Doi: 10.3390/su14031221.
8. Dragne C. CAX Software - The Next Level in Computer Aided Technology. International Journal of Advances in Engineering and Management – IJAEM. 2023; 5(7):551-561. Doi: 10.35629/5252-0507551561.
9. UE website – Industry 5.0: https://ec.europa.eu/info/research-and-innovation/research-area/industrial-research-and-innovation/industry-50_en (accessed on May 10, 2024).
10. McCarthy J. Generality in artificial intelligence. Communications of the ACM. 1987; 30(12):1030-1035.
11. Merlet JP. Advances in the use of neural network for solving the direct kinematics of CDPR with sagging cables. In International Conference on Cable-Driven Parallel Robots (pp. 30-39). Cham: Springer Nature Switzerland, June, 2023.
12. Dragne C. AI in Mechanical Design: Generate Specific Components, Proceeding of the 4th International Conference on Computational Intelligence (ICCI 2023), 2023.
13. Young K, Pickin CG. Accuracy assessment of the modern industrial robot. Industrial Robot International Journal. 2000; 27(6):427-436. Doi: 10.1108/01439910010378851.
14. Zhu X, Liu Z, Cai C, Yang M, Zhang H, Fu L, *et al*. Deep learning-based predicting and compensating method for the pose deviations of parallel robots. Computers & Industrial Engineering, 2024, 110179.
15. Dragne C. New Parameters for Kinematic Performances of Hexapod Robots, 8th International Conference on Engineering Research and Innovations-(ICERI-2023), 2023.
16. Dragne C, Todirite I, Iliescu M, Pandelea M. Distance

Assessment by Object Detection for Visually Impaired Assistive Mechatronic System, Mechatronics and Robotics in Vehicle and Medical Applications Jr., ISSN 2076-3417, MDPI Appl. Sci, 2022. https://www.mdpi.com/2076-3417/12/13/6342., Doi: 10.3390/app12136342 WOS.
17. Stewart D. A platform with six degrees of freedom, Proc. Inst. Mech. Eng. 1965; 180:371-386.
18. Merlet JP. Direct Kinematics of Parallel Manipulators, IEEE Transactions on Robotics and Automation. 1993; 9:842-845.
19. Fiorini Paolo. History of Robots and Robotic Surgery, the SAGES Atlas of Robotic Surgery, 2018.
20. Neto P, Pires J, Moreira A. Robot Path Simulation: A Low-Cost Solution Based on CAD, IEEE Conference on Robotics Automation and Mechatronics), Singapore, June 28-30, 2010.
21. Wang R, Liu L, Xu F. Research on prognostics technology of robot system. Machine Tool and Hydraulics. 2008; 30(11):15-19.
22. Dragne C, *et al*. Damage detection and smart warning for eventual structure failures in mechatronic systems, IEEE World Conference on Applied Intelligence and Computing -AIC 2022, June 17-19, 2022.
23. Tiwari Rudra. Ethical and Societal Implications of AI and Machine Learning, 2023. Doi: 10.55041/IJSREM17505
24. MATLAB Homepage. https://www.matlab.com/, last accessed 2024/01/10.
25. SOLIDWORKS-Homepage. https://www.solidworks.com/, last accessed 2024/02/05.
26. GRABCAD author codes. https://grabcad.com/ciprian.dragne, last accessed 2024/04/08.
27. Greenway B. Robot accuracy. Industrial Robot. 2000; 27(4):257-265. Doi: 10.1108/01439910010372136.