ADAPTION OF COMMERCIAL OFF THE SHELF MODULES FOR RECONFIGURABLE MACHINE TOOL DESIGN

Khumbulani Mpofu
Faculty of Engineering and Built Environment
Tshwane University of Technology,
Pretoria, South Africa
mpofuk@tut.ac.za

Christopher M. Kumile
Faculty of Engineering and Built Environment
Tshwane University of Technology,
Pretoria, South Africa
cmkumile@tut.ac.za

Nkgatho S. Tale
Mechatronics & Micro Manufacturing
Council of Scientific and Industrial Research,
Pretoria, South Africa
ntlale@csir.co.za

Abstract- **A variety of methodologies have been utilised in the design of reconfigurable industrial machines. Authors consider some of the methods that have been used given the critical aspects of these methods, the commercial off the shelf (COTS) method of design of machine tools to achieve flexibility through reconfigurability is discussed. Highlights of the implication of this method and it's repercussions to basic modules, alternate modules and additional modules are analysed. The role of the computer in the entire process is to be particularly highlighted.**

Keywords: off shelf machine design, integration

I. INTRODUCTION

Machine design has conventionally followed a methodology where by a range of concepts are developed then one is chosen for further development and refinement. In the design of reconfigurable machine tools the same trend has been taken by a significant number of researchers. Having realised that the subsystems of the machine are also available as discrete entities, noting as well that these are sold as spares, they can also be gathered to create a database or library of modules which can be used to assemble a modular machine as per customer requirement. In the development of products there are mainly two types of products, the integral product development and the modular product development. A distinct definition is given by Stone, Wood and Crawford [1] who clarifying the disparity of product types as follows "An integral architecture is defined as a physical structure where the functional elements map to a single or a number of very small physical elements". On the other hand "Modular architectures are physical product sub structures that have a one-to-one correspondence with a subset of a product's functional model" [1].

Section II of this paper will consider the methods in machine tool design clearly indicating why the commercial off the shelf (COTS) approach is favourable. The approach used at other institutions is discussed and then the COTS is dwelt on. Section III presents the general machine tool structure and the fourth section presents the models that have been used to configure different machine tools.

II. METHODS IN MACHINE TOOL DESIGN

The perspective taken in the architectural development of the industrial machine tool is the use of commercial off the shelf (COTS) development. This method builds the machine tool based on the commercially available functional units as opposed to the integral design of the machine tool then later on breaking it down into constituent modules. There is a wide range of approaches in designing machine tools the researchers consider two different approaches below. However first the pro's and cons of the conceptual approach are deliberated on then the reasons for selecting the off shelf are stated.

A. Disadvantage of Conceptual / Integral Approach

1. The high cost in the design of the machines.
2. Rigidity of machine tools created using this methodology.
3. Lack of standardization in the machines.
4. The difficulty of integrating the machine subsystems from different vendors.

B. Why Off-shelf Modular Approach

i. The normal root in design of machine tools has been to design the concepts of the final machine then break it down to it's respective modules. Modularity has often been an afterthought [1]. However if modularity is identified and exploited in the initial conceptual or reverse engineering effort the immediate product design reaps benefits in reduced development time and costs.

ii. Modular machines have been available but however they have not been designed to be reconfigurable thus the advantages that can be harnessed from changing the configuration of the machine tool consequently reaping the long lifespan benefits of the machine tool are forfeited.

iii. There is a need for a new body of knowledge in machine tool design with respect to reconfigurability and modularity. This knowledge base would redound in the realisation of better productivity of the manufacturing sector and its competitiveness in the rapidly changing global market needs.

iv. The product life cost of the modular machine will be lower as the time in developing new concepts as the market needs change will be shorter. As will be realized in the deliberations later on, there are some basic modules that will virtual not change and only a selected portion of the entire module assembly has to be designed and fitted to meet new customer requirements. Thus the cost of designing the entire machine tool will be less costly.

v. Standardisation will be encouraged in both the local and international machine tool industry, in a bid to find module integratability.

C. Institutional Machine Design Approaches

In this section the approaches to the machine tool design from an American institute and a European university are considered. There is a wide disparity in the views held by the two institutes but however to some degree both institutes attain to a degree of reconfigurability and modularity in their design of the machine tool or tools that they designed.

A. *University of Michigan (USA) Approach to machine design.*

At Michigan the arch-type is the most common reconfigurable machine tool (it is noted however that this machine tool is not fully modular) that the university developed and the methodology in its development is in five steps as follows;

1. Interpret the requirements and figure out what is necessary given the operation plan.
2. Select the reference machine design using the pre-compiled database which is based on the configuration information and the required motions.
3. Build the function structure graph using the motion requirements and the selected reference design.
4. Complete the connectivity graph and search the available machine modules.
5. Complete the solution graph into the connectivity graph.

In summary the RMT design by Moon [2] is such that it uses modular machine modules and integrated reconfigurability to optimize performance of the RMT.

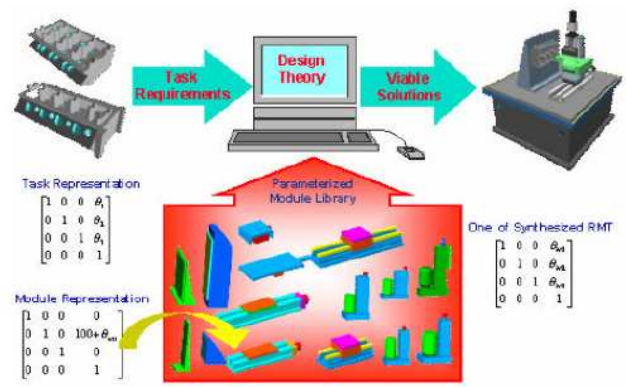

Fig. 1 Overview of machine tool design methodology [Moon & Kota][3]

B. *University of Ljubljana (Slovenia) Machine Design Approach.*

Butala and Sluga [4] view the architecture of the machine tool as a system structure which is reflected in its configuration and which impacts the systems performance. The interfaces of the system are depicted by interfaces between a process and other working system elements, as illustrated in *Figure 2*. They construct their understanding of the system around the ‘elementary work system’ as a reasonable representation of the architectural issues of the reconfigurable machine tool.

A process implementation device (PID) in a machining work system they articulate is a machine tool, composed of three subsystems;

1. The Positioning subsystem- between the tool and the work piece
2. The Kinematic subsystem- providing relative process motions in terms of the cutting speed and the feed rate.
3. Energy subsystem- Delivers required energy for machining.

These subsystems which may be viewed as the major components are complimented by the minor subsystems such as the following;

- The interface between the tool and the machine.
- The interface between the work-piece and the machine.
- The interface converting coded references to control signals.
- The amplifiers and converter of control signals.
- The parameters enabling closed loop control.

Butala and Sluga [4] describe the cutting process view whereby each surface generating machining process can be classified into translation and rotation process movements. This approach was also implemented in a computer aided planning system, they clarify the need of having the features to be implemented embedded in the collective drives that constitute it. This resulted in an adaption of the methodology for the design of reconfigurable assembly systems.

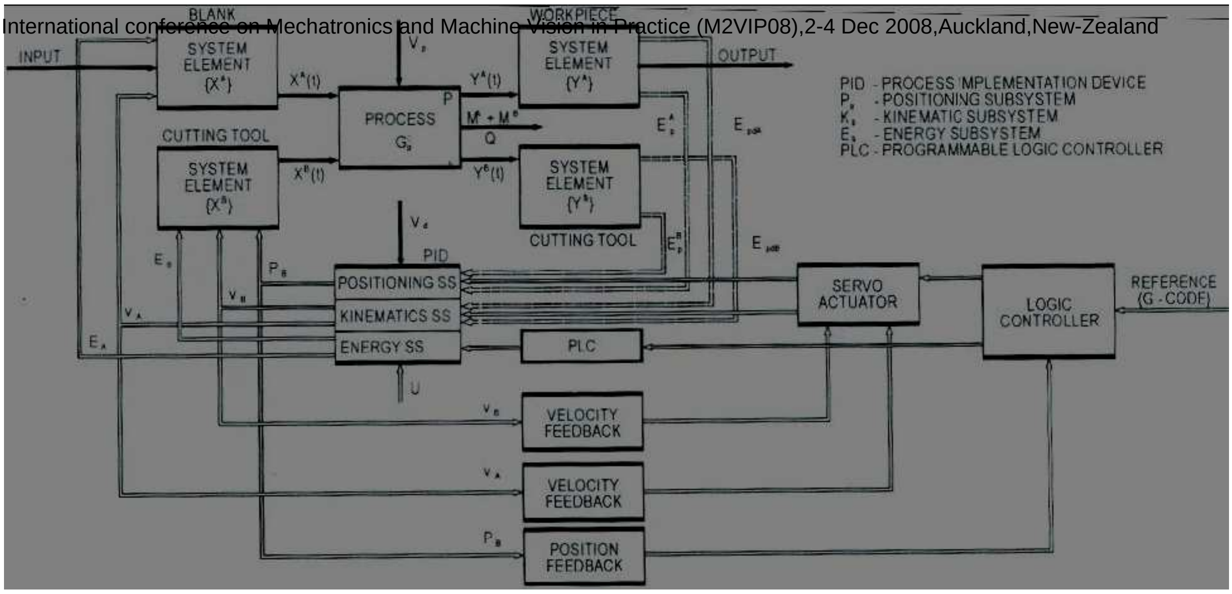

Fig. 2: Elementary work system structure according to Peklenik, 1988[4]

D. Commercial Off Shelf Approach

1. A decision is made on the machine tool that is required.
2. The machine tool is broken down into its respective constituent modules or sub systems.
3. Search for the individual modules from the database of commercial off shelf modules which has been developed from the internet.

   a. The library is created by reflecting on the needs available in the industries of concern.
   b. The modules are classified for ease retrieval from the database as the needs will be arising.

4. Establish different configurations of the machine tools.

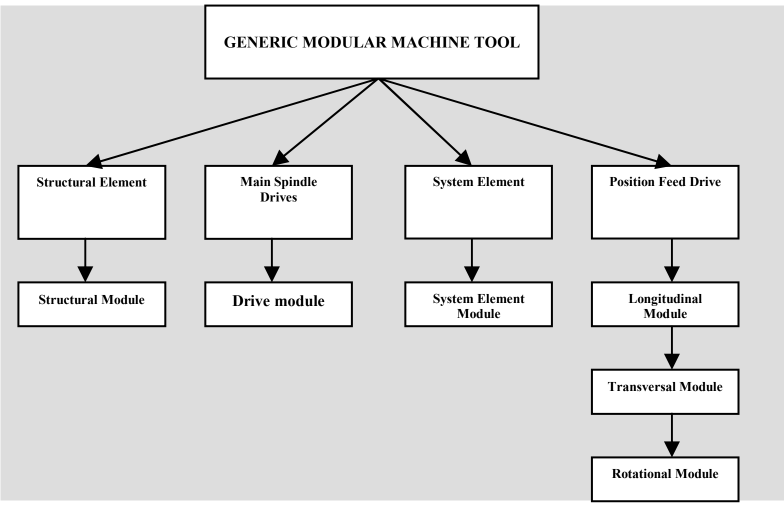

Fig. 3 Generic Module Machine Tool Representation

A tree diagram (as shown in fig 3) maybe used to represent the modules that constitute the machine tool in general. In this diagram only the basic modules can be included.

From this general view the specific modules that comprise a particular machine tool can also be represented in tree diagrams.

When analyzing the specific machine tool tree diagrams it is noted that there are standard modules for any machine tool then there are modules that are specific to a particular machining process. It is also important to note that when focusing on a particular machining process for instance looking at milling there are variations within the machining process the mill could be vertical, it could also be horizontal. This configuration change will also result in the change in the necessary modules to fulfil the needed functionality.

IV Pictorial Representation of the COTS Designs

In this approach in the design of the reconfigurable machine tools the modular components that are available on the internet where made use of. These where downloaded in the pursuit to constitute a database of modules, these being for utilization when designing such reconfigurable machine tools. The four concepts (A, B, C & D) represented here serve as an indicator of the possible configurations and reconfigurations with the available modules. It is noteworthy that this is not an exhaustive range of the machine tool configurations that can be achieved. The authors observe that the modular machine structural configurations reflect the fact that there are modules that are basic (part of every structure), then there are those that are adaptable (for example it functions equally well vertically and horizontally) and there are those that are alternate (a similar role can be played by another totally different module).

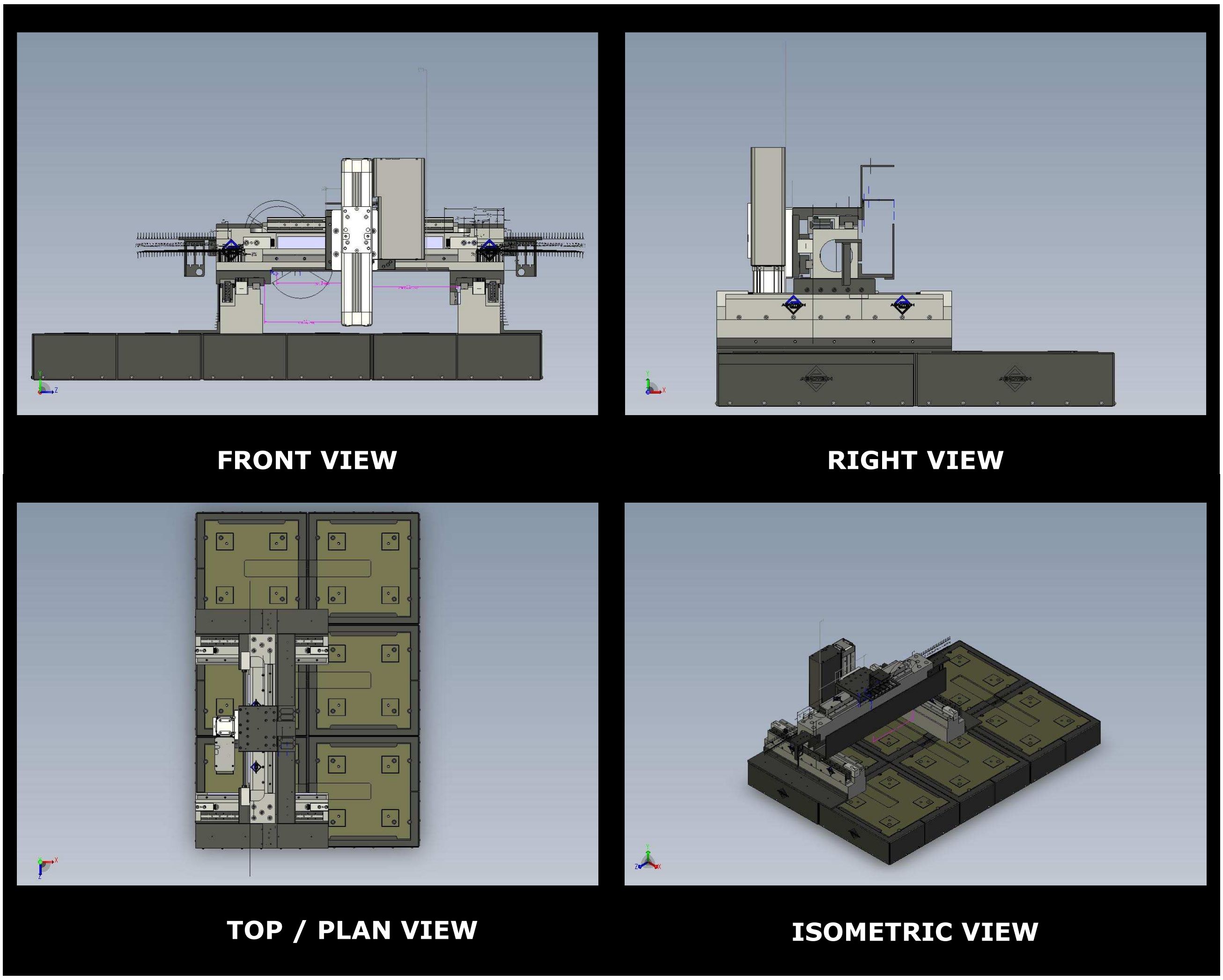

Fig. 4: 3-Axis Machining Concept A for RMT

A: Concept A

In concept A (fig. 4) the commercial off the shelf modules provide an RMT with the following features;

- 3-axis machining is possible in this arrangement.
- The worktable can either be rotary or non rotary depending on the customer's interests.
- The tool is held in the vertical direction and a wide range of tools can be configured as per need.
- Other additions like the tool change platform are also possible.

The diagram gives a clear indication of the maneuverability of the machine tool and the characteristics of integratability are possible as needed by a particular customer.

B: Concept B

Concept B as illustrated in fig. 5 in this arrangement the tool holder is fully supported by the horizontal arrangement of the module that carries it compared to it's positioning in the vertical location as depicted in concept A. Other features are as follows;

- 2 axis machining is achieved with the module components.
- The worktable can either be non rotary or rotary, it may also be placed on x-y slides adding to the degrees of freedom.
- The tool is held in the horizontal plane and executes its machining operations in this direction.
- The Design is inclusive of a tool change arrangement for speedy tool change.
- Grinding, milling turning operations are feasible.

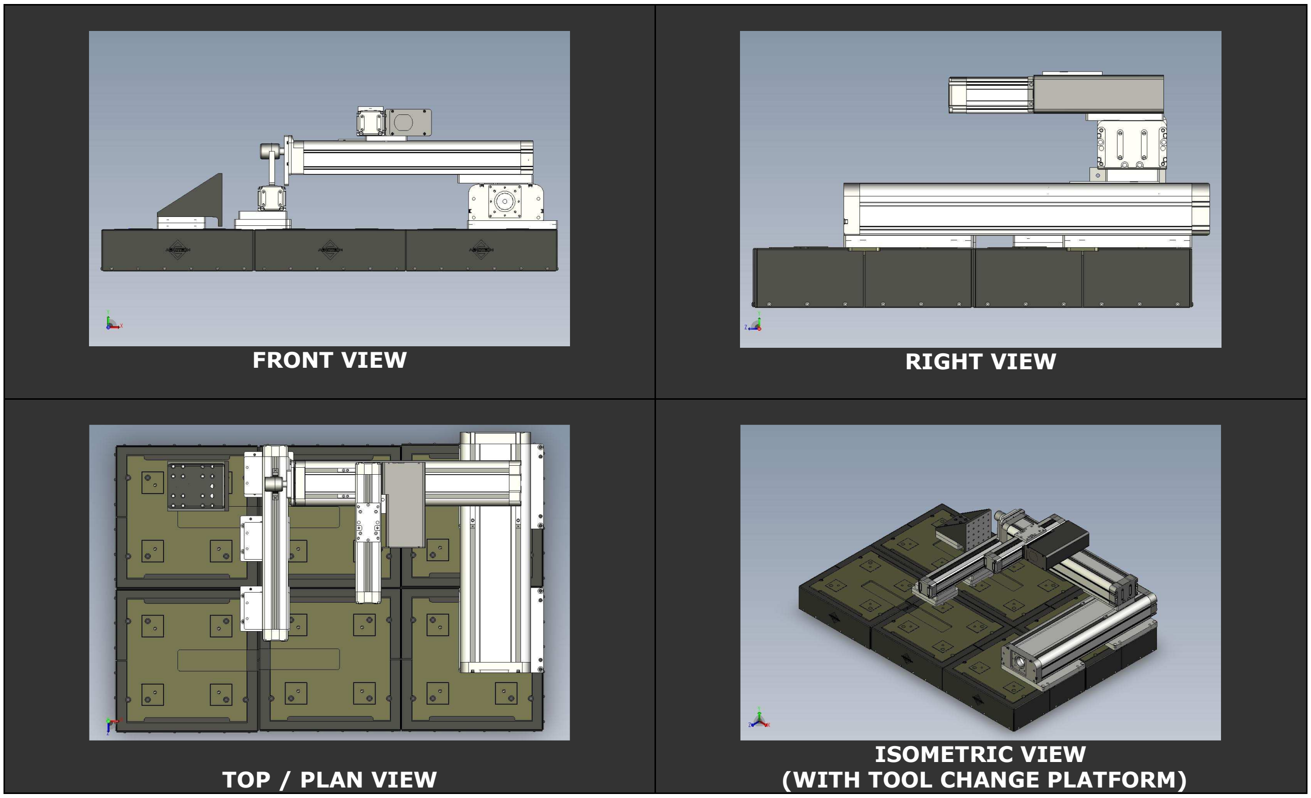

Fig. 5: 2-Axis Machining Concept B for RMT

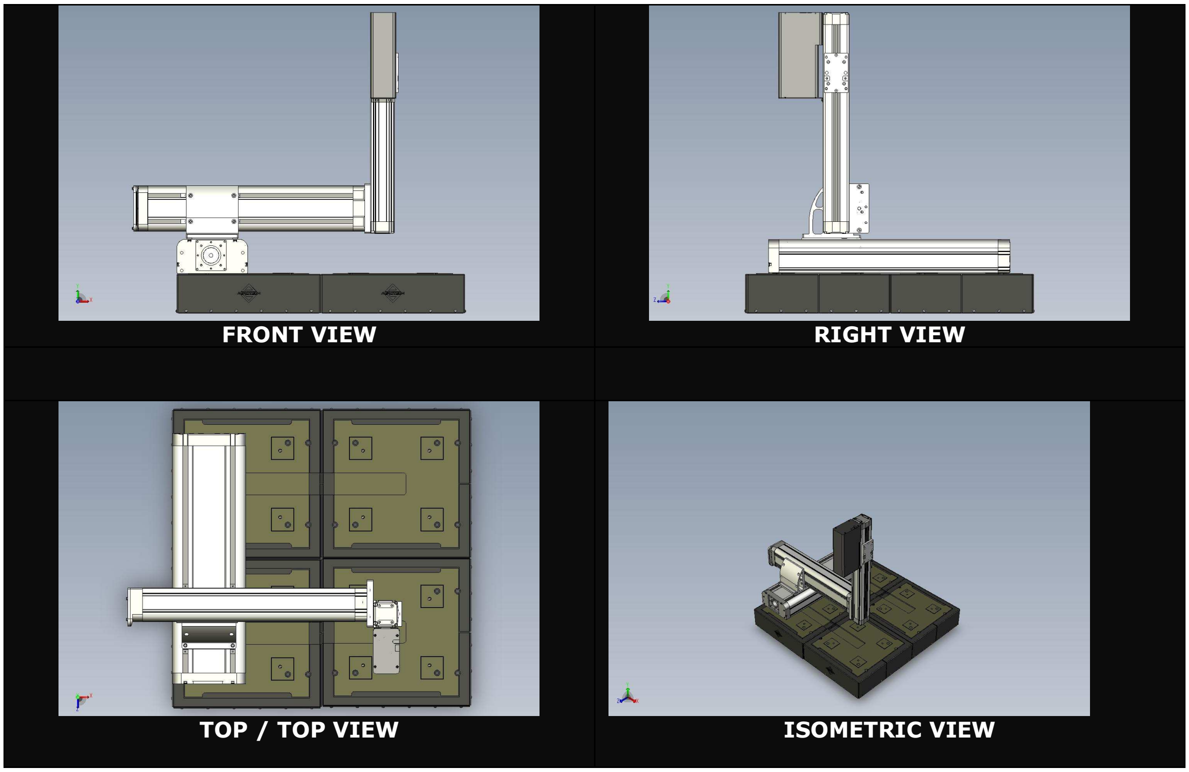

Fig. 6: 3-Axis Machining Concept C for RMT

C: Concept C

Concept C (fig 6) has the following characteristics;

- 3-axis machine (x, y & z motions).
- A rotary or non rotary worktable can be implemented. This will result in addition of the degrees of freedom for the machine tool.
- A variety of machine tool holders can be added and thus the capability to execute milling, drilling and turning operations.
- The tool has a vertical orientation.

Convertibility, scalability and adaptability are achievable goals for the RMS characteristics realisation, following the described machine configurations.

This design has a relatively larger workspace capacity in comparison with the other configurations but however the stability of the structure is very low.

D: Concept D

In fig 7 there we have the following;

- 2-axis machine.
- A rotary work platform adds to the degrees of freedom.
- A variety of machine tool holders can be added and thus the capability to execute milling, drilling and turning operations.

Included in his design is a rotary platform which will increase the application possibilities in the final application of the machine tool.

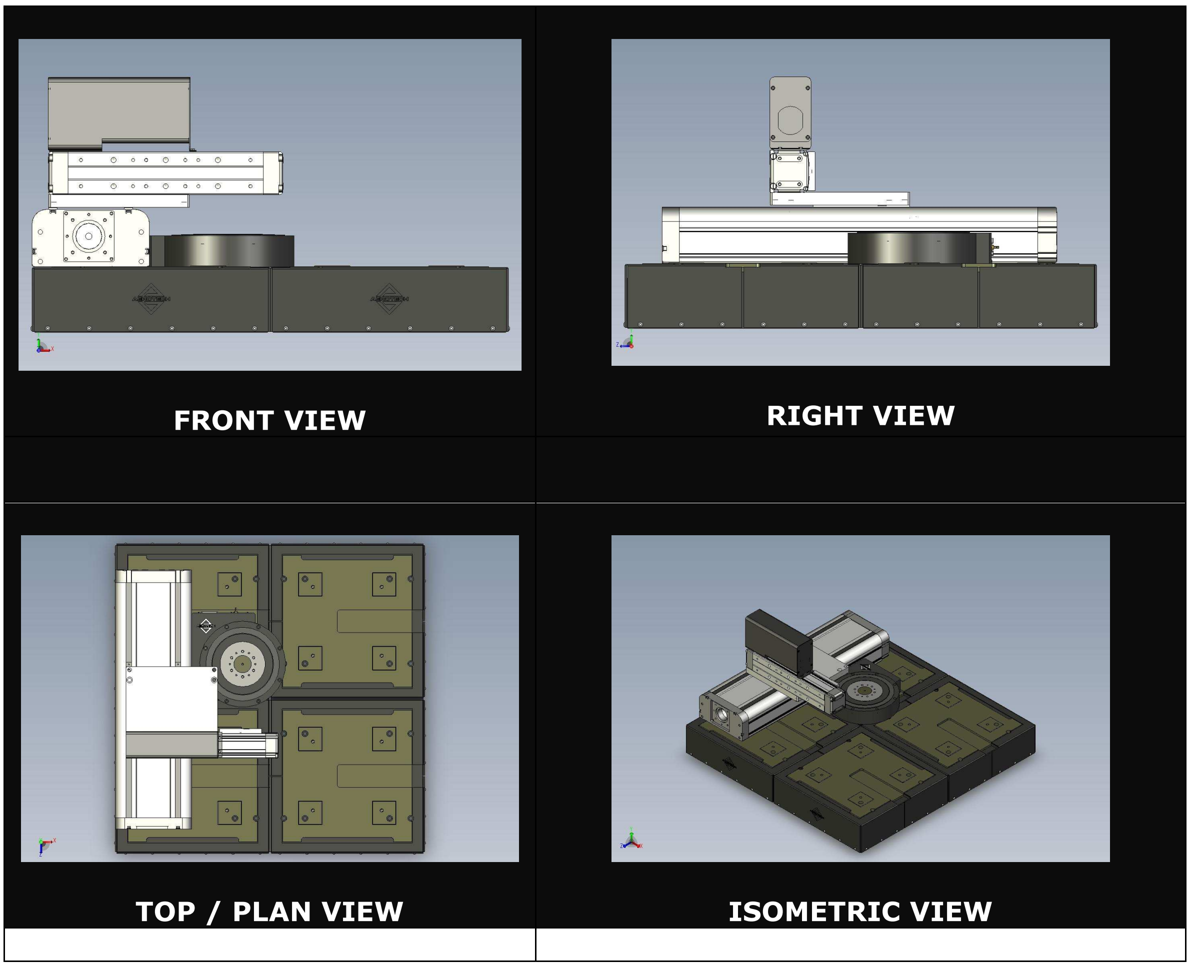

Fig. 7: 2-Axis Machining Concept D for RMT

DISCUSSION

1. The machine tool design method at Michigan is focused on the requirements for the machine tool being designed. The method adopted at University of Ljubljana views the machine tool as a system with major systems and minor subsystems. The COTS method we follow seeks to intergrate these two views.
2. At Michigan a set of preconceived modules is used to constitute the machine tool. However in our approach we seek to continually update our database as new modules become available in the web.
3. The development of a knowledge based system to help in the configuration and reconfiguration of the machine tools is part of the desired outcome in this work. This will help in the store of both the retrieved modules and the varying machine tool configurations.
4. Development of a system to search for modules on the web and download them directly into our database of modules is also a direction being pondered.
5. Looking at the industrial application authors for see that depending on the machine end users capacity the purchase of these softwares maybe expensive for small organisations but for a bigger organisation the investment maybe worth the returns for the variable machine configurations such an organisation would have with respect to its market.

SUMMARY AND CONCLUSION

Two methodologies utilised in the specification of reconfigurable machine tools are analysed, then an approach is proposed in the configuration and reconfiguration of these industrial machine tools.

Authors further on go to present the range of varying configurations that are achievable with these commercial off shelf modules. These mechatronic modules can result in structures of machine tools that are reconfigurable and the characteristics of the RMS can also be realised as depicted.

Future work will involve searching for the suitable work part holding mechanisms that are modular and the respective tool holders are yet to be integrated into the designed structure. It will also involve the simulation and finite element analysis of the proposed methods. The stability and stiffness tests will also be carried out, issues that will also need to be taken into consideration of are the rump up time for changing from one configuration to the next. The reconfiguration time and it's optimisation becomes a critical issue in the industrial application of these machine tools. Thought will also need to be pondered on, with respect to the implications of the modular designer of the machine tool to the manufacturing system utilised to develop the modular tool. Aspects in these lines are hinted on by Erixon et al [7].

ACKNOWLEDGMENT

K. Mpofu thanks Tshwane University of Technology and the Advanced Manufacturing Strategy for the privilege to undertake this research.

REFERENCES

[1] Stone, R. B., Wood, K. L. and Crawford, R. H. (2000). A heuristic method for identifying modules for product architectures, *Design Studies* **20** 5-31.

[2] Moon, Y. M. (2006). Reconfigurable machine tool design, *Reconfigurable manufacturing systems and transformable Factories*. (Edited by A.I. Dashchenko), 111-137. Springer-Verlag : Berlin Heidelberg.

[3] Moon, Y.-M., and Kota, S. (1999). Design of Reconfigurable machine tools: In *proceedings of CIRP International Seminar on Manufacturing Systems*, **32** 297-303.

[4] Butala, P. & Sluga, A. (2002) Morphology of reconfigurable manufacturing systems: In *Proceedings of the International Workshop on Emergent Synthesis IWES '02*: **4** 127-134.

[5] K-M. Chen, and R-J. Liu, Interface strategies in modular product innovation. *Technovation* vol. 22, pp. 771-782 2005.

[6] Beitz, W., Feldhusen, J., Grote, K. H , and Pahl, G. (2007). *Engineering Design: A systematic approach. (* 3rd), Springer-Verlag : London

[7] Erixon G., Yxkull A., Arnstrom A., Modularity-the Basis for Product and Factory Reengineering. *Annals of the CIRP* 45/1 pp. 1-6 1996.