Factory Planning Through Paper-based Computer-Aided Sketching

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Abstract: Sketching has long served as a means to quickly express ideas in the early stages of design. Whilst CAD systems offer visualization capabilities that are not offered by a sketch, such technology is not exploited in the early stages, as it does not allow sketching as input. For this reason, Computer Aided Sketching (CAS) technology has been developed to combine the benefits of sketching with CAD. Yet, although this technology has been applied in a range of domains (such as architecture, product design, graphical user-interface design etc.), it has not yet been exploited for shop floor planning. In view of this, the research disclosed in this paper concerns the on-going development of a framework allowing users to quickly have a 3D CAD model of a factory directly from paper-based sketches of the factory. A visual language was developed such that it allows factory designers to schematically represent the shop floor, whilst at the same time facilitates off-line computer-processing of the sketches.

Key words: Digital manufacturing, conceptual design, sketch recognition, 3D visualisation

1 – Introduction

Sketching is a great aid during the design process since it is effortless and very natural since people learn to sketch as very young children [1]. Moreover, sketching helps the designer to concentrate all the effort on the design process since sketching occupies zero cognitive load [2]. One of the key roles of sketching throughout the design process especially during early stages, is graphical communication [3]. In fact, designers and engineers generally use sketches to tackle new design problems [2] because it provides a quick and easy way to externalize [3], evaluate, modify, refine and replace design ideas [2]. Due to its efficacy in rapidly externalizing form concepts, freehand sketching is used in various domains, besides product design. Shop floor planning is not an exception. The planning of a factory needs to be fast and flexible to respond to the increasing demands for product varieties and customer-driven design [4]. To this end, sketching plays a key role in quickly outlining a new layout of the factory to support the manufacture of customized products. On the other hand, a three-dimensional (3D) virtual model of the factory would be of great benefit, especially for visualization purposes.

Further to this one has to consider the ever increasing pressure to reduce cost and time whilst maintaining high levels of quality in product development scenarios. As discussed by Westkämper [5] for the European industry to remain competitive under increased economic uncertainty, a change in the paradigms of industrial manufacture is required. In fact in the implementation of the ManuFuture document [6], one of the driving forces identified is the application of ICT in manufacturing.

In spite of this scenario, a tool which supports engineers to automatically obtain a virtual factory layout directly from paper-based sketches does not exist.

The rest of this paper is structured as follows. Section 2 discusses related work on Computer-Aided Sketching and on technology targeted specifically for factory layout design. Section 3 presents the framework architecture developed to translate factory layouts sketched on paper into 3D virtual models. Section 4 focuses on the symbols used in the visual language developed for this application. The subsequent section treats the implementation of a prototype tool. Section 6 discloses preliminary results of an evaluation carried out to assess the implemented prototype tool. A discussion follows in Section 6. Future research directions are also recommended. Finally, Section 7 draws conclusions from this work, with focus placed on the contribution disclosed in this paper.

2 – Related Work

CAS technology has been developed in various domains, including freeform surface modelling [7] and hair styling [8] to mention but a few. When it comes to floor plans, the systems found are dominantly related to architecture such as the work by Do [9] and the *EsQUIsE* system [10]. Whilst the 3D modelling capabilities of these systems are quite extensive the traditional paper sketching is replaced with digital sketching. Commercial systems for translating floor plans sketches into 3D models are also available, such as *Google SketchUp* [11] and *CAD Pro* [12]. In these two systems the user imports a scanned image of the freehand sketch which is traced over to outline a profile for 3D modelling. This means that the 3D CAD model is not generated automatically from the original paper-based sketch. With regards to existing support targeted specifically for factory planning, rather than sketching interfaces, tangible user interfaces were found. For instance the factory planning table described in [13] utilizes sheets of paper to represent the shop floor and metal objects to symbolize different machinery and processes. The factory planning table enables the planning team to obtain a 3D CAD model and view a simulation of factory layout in real-time [13].

Commercial software such as *Tecnomatix*, developed by Siemens PLM software is also available [14]. This software incorporates a number of applications dedicated to the planning, management and optimization of manufacturing processes and enterprises. One of the software's main features is on plant design and optimization which incorporates factory simulation made up of two modules – *FactoryCAD*, which is capable of producing a detailed 3D layout of the factory or shop floor and *Plant Simulation* which models, simulates and optimises the production system and logistics processes of the layout developed in the *FactoryCAD*. Although *Tecnomatix* offers cutting edge software in the factory and process planning industry, its applications still use the traditional way of information input, that is, the user has to use a computer and manually manipulate and arrange the 3D models.

3 – Framework Architecture

To address the gap found in literature in linking paper-based sketching with 3D CAD modelling of the factory, the framework architecture illustrated in Figure 1 has been developed. The framework is constituted of the following frames:

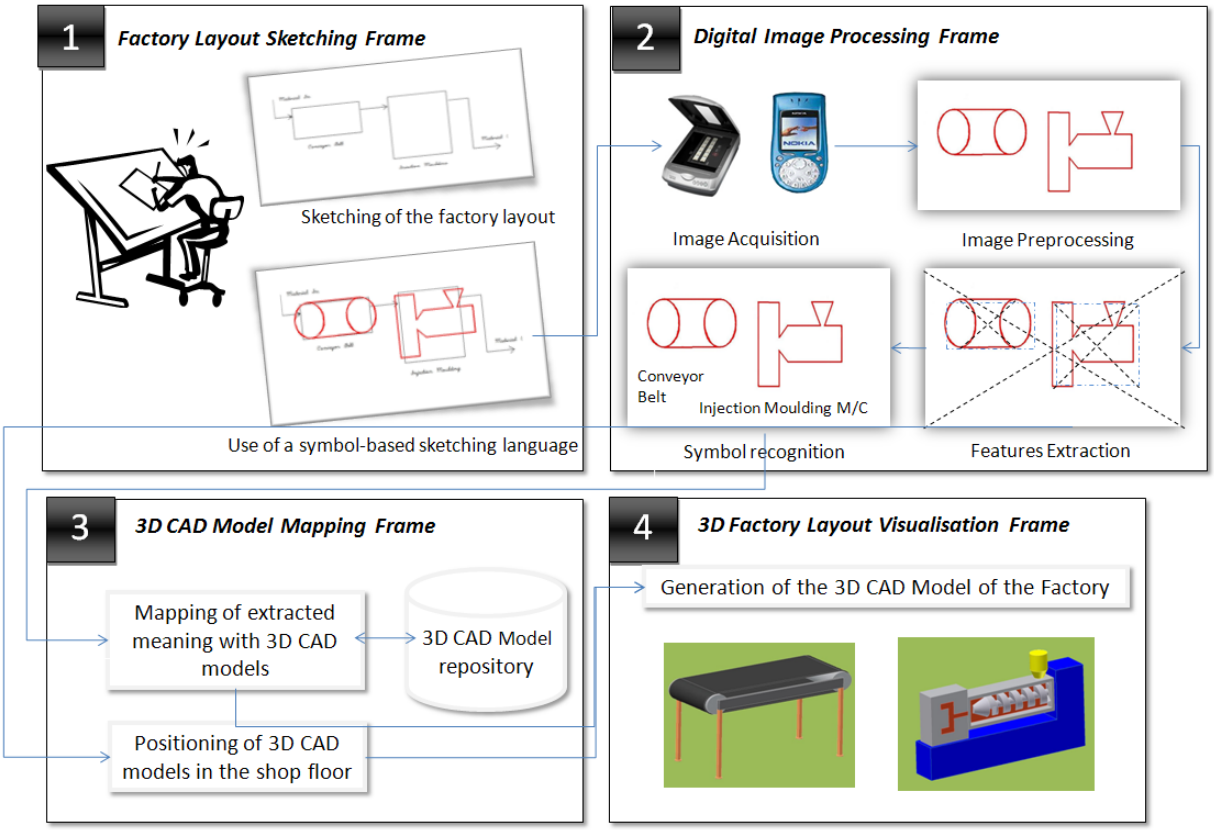


Figure 1: Framework architecture

1. *Factory Layout Sketching (FLS)* frame: in this frame the manufacturing engineer is first allowed to sketch on paper the 2D plan of the factory in his/her own sketching style. Owing to the difficulties of a computer in recognizing freehand sketches, the engineer then annotates the freehand sketch with a prescribed sketching language (*PSL*), which is detailed in the next section. A coloured pen is utilized in order to facilitate further the processing of the sketch.
2. *Digital Image Processing (DIP)* frame: where an image of the annotated sketch generated in *FLS* frame is captured by means of either a flatbed scanner or a cameraphone. In this way, the *DIP* frame enables users to capture and process a digital sketch image when they are located on site, where the new layout of the factory will be implemented. A number of image pre-processing stages are then applied on the image, including binarisation (i.e. having black pixel sketching elements on a white background), noise removal (e.g. noise blobs introduced in the image), image

component labelling and skeletonisation (reducing the thickness of the sketching language elements) to one pixel. After image pre-processing, the features of each symbol are extracted. As illustrated in Figure 1, an example of such a feature is the centre point of the minimum bounding box enclosing the symbol. The features which are extracted are exploited both for the positioning of a particular machine in the generation of the 3D CAD model and also as basis for symbol recognition.

3. *3D CAD Model Mapping (3DCADM)* frame: converts the information obtained from the previous frame into a 3D model of the shop floor. The meaning assigned to the recognized symbol is mapped into the corresponding 3D CAD model stored in a repository. In addition, a 3D CAD model is placed in the shop floor according to the coordinates of the symbol extracted in the DIP frame.
4. *3D Factory Layout Visualization (3DFLV)* frame: basically the scope of this frame is to present the 3D CAD model of the factory layout to the user from the original input sketch.

3 – Language Symbols and their Meaning

This tool is primarily aimed at providing support for a group of experts during the initial concept design stages of factory planning and therefore the symbols were designed irrespective of a particular machine make or type since at these initial stages details are not important. Also since this research is in its infancy, the symbols of the sketching language were limited to ten. Nonetheless, the symbols were chosen such that they represent a wide range of manufacturing processes commonly found in industry. These can be categorised into two main classes:

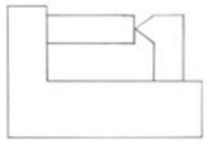
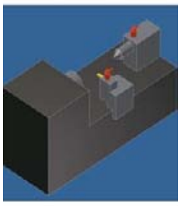
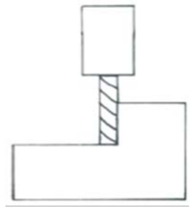
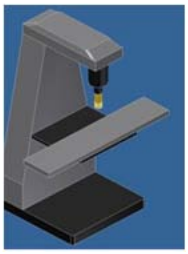
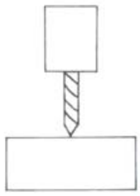
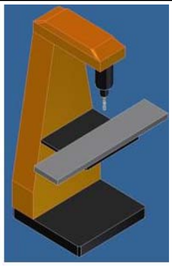
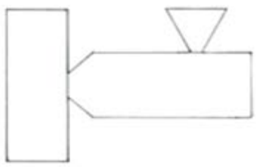
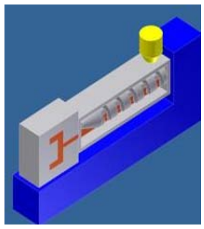
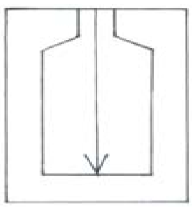
1. conventional: machining processes including turning, milling and drilling, and forming processes, including plastic blow moulding and injection moulding;
2. non-conventional: spark erosion and wire electro-discharge machining (*EDM*).

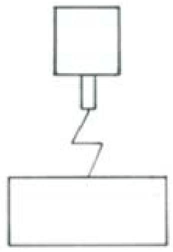
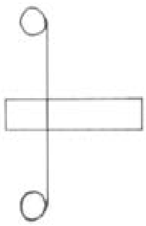
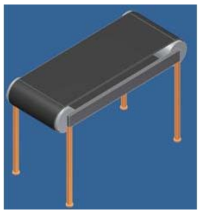
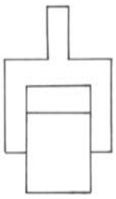
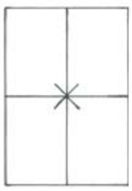
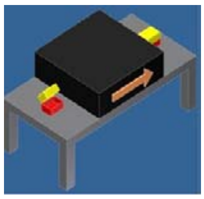
In addition two material handling techniques, more specifically a conveyor belt and loading were taken into account. The closing assembly procedure (e.g. the closing of a make-up case) was also considered.

The symbols were designed on a compromise between preserving sketching freedom and the formality required for computer recognition. Therefore, a set of specifications were prepared in order to achieve the most suitable symbols. These specifications consisted of simplicity, quickness-to-draw, consistency on the one hand, and distinctiveness and connectivity on the other hand [15].

In order to choose the symbols that best represent a particular process, a survey was distributed amongst sixteen mechanical engineering students and four mechanical engineering workshop technicians. The participants had to rate the most suitable symbol from a set of three symbols proposed to represent a particular process. Interestingly the survey results revealed that symbols that are characterised by letters to represent a particular process (e.g. 'M' for milling) were rejected by the participants. In addition, from the survey it emerged that 60% of the participants preferred symbols that depict the process from a side view rather than from a top view, even though the symbols are used in 2D plans. Table 1 illustrates the resulting set of symbols and their corresponding 3D CAD models.

Table 1 - Symbols & equivalent 3D models

	Symbol	3D Model
Conventional machining processes	Turning machine 	
	Vertical milling machine 	
	Drilling machine 	
Conventional forming processes	Injection Moulding machine 	
	Blow Moulding machine 	

Non-conventional machining processes	Spark Erosion machine 	
	Wire EDM machine 	
Material Handling	Conveyer belt 	
	Robot 	
Assembly Procedure	Closing 	

4 – Prototype Tool Implementation

Matlab® was used in the implementation of a prototype tool, since it has off-the-shelf algorithms in the image processing and neural network toolboxes which can be readily utilized for this application. The first image pre-processing task consists of separating the coloured language symbols from the underlying pencil sketch. To accomplish this task, the function *rgb2ind* [16] in the image processing toolbox (IPT) has been applied on the image. This function converts an *RGB* colour image into an indexed image, where each pixel is assigned an integer whose value corresponds to one of the indexed colours represented in a colourmap matrix [16]. This is followed by binarisation of the *PSL* sketch image in which the *PSL* elements are constituted of black pixels on a white background. Noise blobs which are introduced during scanning are then removed. The *IPT* function bwmorph [16] is then applied to achieve a skeletonized image. By considering 8-connectivity between the constituent black pixels, each symbol in the image is then uniquely labelled for classification purposes, by the *IPT* function *bwlabel* [16].

Once all the symbols are uniquely labeled, their features are extracted. These include the length (L) and width (W) of the symbol and the centrepoint (C) of its minimum bounding box. The tool calculates a scaling factor which translates unit measurements from dpi into mm. In addition, the tool automatically calculates a scaling factor in order to enlarge the sketch to eventually accommodate the 3D CAD models. To achieve this, the tool divides the length of the actual 3D model by L. This step also eliminates the possibility of overlapping 3D models. Other features are extracted from each symbol for classification purposes, More specifically, each symbol is represented by an $R \times 1$ vector. The values in the rows R are extracted as described in [17]. First the original symbol image is cropped around its border and dilated whereby pixels are added to the boundaries of the symbol. The dilated image is resized into an image measuring 70 × 50 pixels and then segmented into 10 × 10 regions, thus ending up with 35 such regions in the 70 × 50 sized object image. Each of these 35 regions is assigned a value between 0 and 1 – the more the region is filled with black pixels, the more the value approaches 1.

Artificial neural networks (ANNs) are being utilized for symbol classification. The main advantage of applying ANNs is that they allow for noise in the input [18] with good performance [19]. For pattern recognition purposes, the ANN with a feedforward architecture trained with backpropagation is widely used [19] and is the one that we are currently investigating for this application. The input to this ANN architecture is made up of the 35 values extracted from the symbol, as explained previously.

The 3D CAD models illustrated in Table 1 have been generated in *Autodesk Inventor*®. They are represented as text files in *VRML V1.0 ASCII* format in the repository of the 3DCADM frame. Since the ANN is still being developed, the mapping of each symbol in the corresponding 3D model is done manually. In addition, the orientation is given by the user and translated in radians about the y-axis by the tool. When the mapping is accomplished, the x-y coordinates of the particular symbol, extracted from image processing, are printed in the corresponding *VRML V1.0 ASCII* format of the 3D model. It must be mentioned that besides the symbols illustrated in Table 1, the user must also sketch the floor plan symbol and the perimeter of the factory. Figure 2 illustrates an example of a sketch which was converted to a 3D model by the prototype tool.

5 – Evaluation

The evaluation protocol consisted of three main steps - a brief presentation on the research work, a live demonstration of the prototype tool and a semi-structured interview with each participant. This evaluation was carried out with a foreign digital factory and grid engineering for manufacturing expert, two factory planners and also two mechanical engineering students. The participants were chosen intentionally in order to have evaluations from a wide spectrum, but at the same time all the participants had a degree of knowledge in this subject. A 7-scale lickert scale was used in the semi-structured questionnaire form to measure the participants' attitude.

The evaluation results suggest that the symbols employed in *PSL* were simple to understand, quick to draw and consistent between each other. However, the evaluators commented that the "developed symbols library has to be shown to the layout planning team." The participants also expressed a positive attitude towards the 3D CAD models mapped from the symbols. The particpants commented that the models were easy to identify and they contained enough detail for the early stage of design. Another important finding was that the majority of the participants (86%) did not find any objection towards the idea of using symbols in sketches to represent the different manufacturing processes. Participants commented that this sketching approach helps the planning team to concentrate more on the planning activities rather than how to create the 3D model. Moreover, others commented that this "innovative idea helps in reducing the planning time" and therefore reducing the time to market.

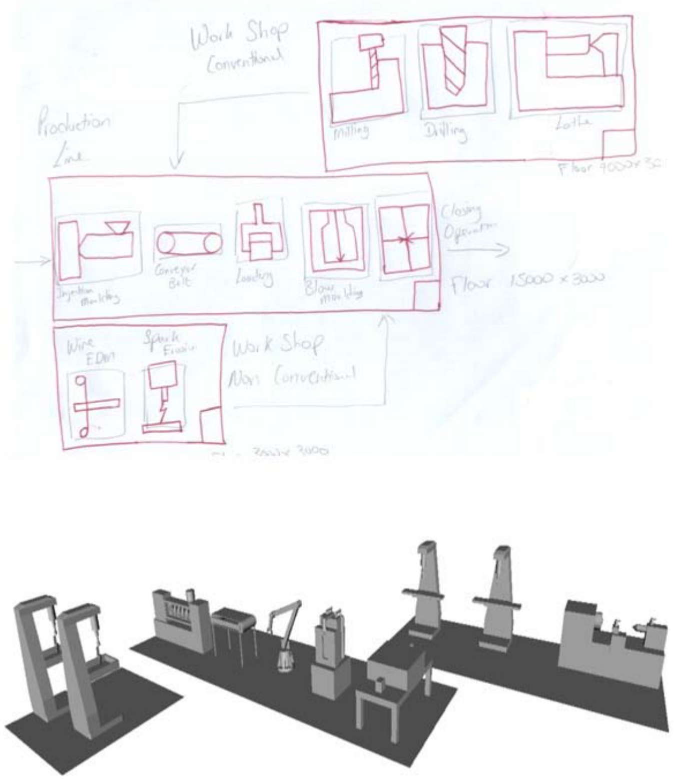


Figure 2: Example of 3D model of a factory produced directly from a paper-based sketch

The participants were also explicitly asked to list the prototype tool's strengths and weaknesses. One of the most common reported strengths was that this tool supports a team-based approach and its use is to aid layout design in the initial stages to create an informal 3D layout. On the other hand, it was commonly pointed out that automatic symbol classification must be implemented to avoid as much as possible manual input. Based on their impressions on the live tool demonstration, the evaluators were asked to express their opinion on the effectiveness of the tool in practice. The majority of the participants answered 'very practical'. The main reasons were that this tool is very quick and easy to use. In addition, the factory design expert commented that there already exists a place for this tool in the current planning process i.e. to support team based rough layout design in the early stages of design where the team is composed of multi-disciplinary experts such as architects, mechanical engineers and accountants. Moreover, she commented that the format used for the 3D models, i.e. *VRML V1.0 ASCII*, is widely used in CAD systems and also research and commercial factory planning equipment, such as those avilable at the Grid Engineering Laboratory - GEMLab at the Fraunhofer IPA/IFF in Stuttgart, Germany. Therefore, this format increases and widens the possible applications of this tool in industry and in conjunction with other established factory layout planning tools.

6 – Discussion and Future Work

From comments and feedback received during the evaluation of the developed tool the objectives set out by this research work have been satisfactorlily met. This said future work has been identified such as to improve the functionality of this tool. To eliminate further the human intervention in this tool, one of the short-term academic goals will be to develop further the symbols in the PSL. One of these improvements will be aimed at automatically detecting the orientation of the process sketches and rotating them accordingly in the 3D model.

Additionaly more symbols in the *PSL* will be investigated such as to increase its useability. It is also planned that during future research activities the number of symbols will be further increased in order to represent different processes that can be used in the final layout. Another interesting direction for this research will be to not only portray manufacturing processes but also to include personnel, material flow and other equipment utilised for material handling so that the final 3D layout can be used to evaluate the factory layout from different perspectives such as the ergonomics of the shop floor.

Hence this leads to one of the long-term research goals being envisaged which would lead to linking this tool with other research and commercial manufacturing and factory simulation software. This can be achieved using the information contained in the outputs of the system. By adding further information from the sketch and the user inputs in the output model generated by the tool, it can then be used to create process plan models of the layout which can be passed on to dedicated simulation software. This model could therefore contain the name of the processes, their positions and orientation, process information and material handling operations. This information is enough to serve as a basis on which a high level manufacturing simulation can be constructed with the use of dedicated software.

It is also planned to use the digital 3D models being generated by this tool directly in tools that use the VRML V1.0 ascii® format, such as Virtual Reality Environments. This eliminates completely the use of CAD software and passes directly to the evaluation of the layout stage therefore further reducing the planning time and costs.

7 – Conclusions

This research started by identifying a gap in the provision of support to factory planners and factory design professionals. Equipment and software used by companies or organisations that specialize in this field, requires high processing power and specialised equipment, therefore it severly lacks portability.

Future work is still required for the tool to meet the stringent requirements of the industrial environment; nevertheless this research has met its objectives by contributing in developing a novel framework that will allow Factory Planners and Designers to work remotely with a minium amount of hardware which is both inexpensive and easily available.

This means that a digital 3D model of the factory layout can be presented to both the customers and technical experts immediately and on site, without the need of waiting until the designer arrives back at the company and constructs the 3D model on specific CAD software. Changes to the layout can therefore be made immediately if the customers' or experts' needs are not satisfied saving both time and money.

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References

[1] Plimmer, B. and M. Apperley. *Computer-Aided Sketching to Capture Preliminary Design*. in *Third Australian User Interfaces Conference (AUIC2002)*. 2002. Melbourne, Australia, pp.9-12

[2] Goldschmidt, G. *The backtalk of self-generated sketches*. in *Visual and spatial reasoning in design*. 1999. Sydney, Australia, pp.163 - 184.

[3] Song, S. and A.M. Agogino. *Insights on designers' sketching activities in new product design teams*. in *ASME 2004 Design Engineering Technical Conferences and Computers and Information in Engineering Conference (DETC'04)*. 2004. Salt Lake City, Utah, USA, pp. 351-360.

[4] Morey, B., *Flexing the Factory*, in *Society of Manufacutring Engineering Magazine - Motorized Vehicle Manufacturing*. 2010. pp. 38 - 41.

[5] Westkämper, E. *Manufuture and Sustainable Manufacturing*. in *Manufacturing Systems and Technologies for the New Frontier*. 2008, pp.11 - 14.

[6] Manufuture high Level group, *Manufuture - A Vision for 2020 - Assuring the Future of Manufacturing in Europe*. 2004: European Commission.

[7] Alexis, A., S. Saito, and M. Nakajima. *CrossSketch: Freeform Surface Modeling with Details*. in *Eurographics Workshop on Sketch-based Interfaces and Modeling*. 2007. University of California, Riverside, pp.45-52.

[8] Fu, H., Y. Wei, C.L. Tai, and L. Quan. *Sketching Hairstyles*. in *Eurographics Workshop on Sketch-based Interfaces and Modeling*. 2007. University of California, Riverside, pp.31 - 36.

[9] Yi-Luen Do, E., *Investigation of Freehand Drawing as an Interface to Knowledge Based Design Tools*. 1998, PhD in Design Computing, Georgia Institute of Technology.

[10] Juchmes, R., P. Leclereq, and S. Azar. *A Multi-Agent System for the Interpretation of Architectural Sketches*. in *Sketch-based Interfaces and Modeling*. 2004. Grenoble, France, pp.53-61.

[11] Chopra, A., *Google SketchUp For Dummies (For Dummies (Computer/Tech)*. 2007: For Dummies (Wiley).

[12] CAD Pro, *CAD Pro 6 Features*, 2010 retrieved from: http://www.cadpro.com/PRODUCTS-c1315-wp4435.htm. Date accessed: 12th February 2010.

[13] Westkämper, E., Sihn, W., von-Briel, R, *Interactive Factory Planning*. in *Software Engineering and Application (SEA 99)*. 1999. Anaheim, CA, USA, pp.224-228.

[14] Software, S.P., *Tecnomatix*, 2010 retrieved from: http://www.plm.automation.siemens.com/en_us/products/tecnomatix/. Date accessed: 23rd April 2010.

[15] Farrugia, P., *Paper-based Computer-Aided Form Sketching - A Prescribed Sketching Language-based Approach -*. 2008, Ph.D., Concurrent Engineering Research Unit, Department of Industrial & Manufacturing Engineering, University of Malta.

[16] Gonzalez, R.C., R.E. Woods, and S.L. Eddins, *Digital Image Processing using Matlab*. 2004: Prentice Hall.

[17] Basic engineering blogspot, *Character Recognition Example*, 2006 retrieved from: http://basic-eng.blogspot.com/2006/04/character-recognition-example.html. Date accessed: 2nd February 2010.

[18] Cheng, T., J. Khan, H. Liu, and D.Y.Y. Yun. *A symbol recognition system*. in *Second International Conference on Document Analysis and Recognition*. 1993. Tsukuba Science City, Japan, pp.918-921.

[19] Bortolozzi, F., A. Britto Jr, L.S. Oliveira, and M. Morita, *Recent Advances in Handwriting Recognition*, in *Document Analysis*, P. Umapada, K.P. Swapan, and B.C. Bidyut, Editors. 2005. pp. 1-30.

