

Agus Sutanto

*Solution Approaches for Planning
of Assembly Systems in
Three-Dimensional Virtual
Environments*

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Environments*

Herausgegeben von

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Lehrstuhl für

Fertigungsautomatisierung und Produktionssystematik

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Vorwort

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Lösungsansätze zur Planung von Montagesystemen in dreidimensionalen virtuellen Umgebungen

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1 Einleitung

Der allgemeine Trend zu immer kürzer werdenden Produktlebenszyklen innerhalb eines sich stetig schneller verändernden Marktumfeldes verlangt auch von der Produktionsplanung eine beständige Weiterentwicklung der in diesem Bereich eingesetzten Werkzeuge und Methoden. Der Wunsch, trotz gesteigerter Planungsgeschwindigkeit ein hohes Maß an Sicherheit bezüglich Anlauf und Betrieb einer neuen Produktionsstätte bereits vor deren Inbetriebnahme zu gewährleisten, geht dabei einher mit dem Bedarf an innovativen Technologien, die den Planer bei der Konzeption einer neuen Fertigungsstätte unterstützen [157]. Verstärkt wird dies auch durch einen Verständniswandel in der Produktionsplanung, der von der Abkehr von einer einmaligen, projektbezogenen Produktionsplanung hin zu einer permanenten, betriebsbegleitenden Planung gekennzeichnet ist [152]. Im Zuge der fortschreitenden Globalisierung wächst ferner die Bedeutung kollaborativer sowie partizipativer Werkzeuge, welche insbesondere für eine erfolgreiche und effiziente Integration aller Planungsbeteiligten und -kompetenzen notwendig sind [51], [92], [133].

Angesichts der vielfältigen Einflüsse und Anforderungen, denen ein modernes, weltweit agierendes Unternehmen ausgesetzt ist, erhält die Planung von Prozessen, Abläufen und Strukturen innerhalb der Produktion eine zunehmend wettbewerbsentscheidende Bedeutung. Einen wesentlichen Beitrag hierzu können moderne, rechnergestützte Werkzeuge zur Produktionsplanung liefern. Durch eine konsequente Digitalisierung sämtlicher Planungsdaten ermöglichen sie eine kontinuierliche und simultane Planung von Fertigungseinrichtungen. Die digitale Verfügbarkeit erleichtert dabei gleichzeitig die Erstellung virtueller Modelle und Simulationsstudien, wodurch Fertigungsprozesse bereits vor ihrer Verwirklichung in der Realität erprobt werden können. Auf diese Weise werden Schwachstellen frühzeitig identifiziert und die Planungsqualität und -sicherheit werden gesteigert, während gleichzeitig die Planungszeit reduziert werden kann.

Die Produktionsplanung in ihrer heutigen Form ist durch einen hohen Grad an Interdisziplinarität sowie einen kollaborativen Charakter gekennzeichnet. Durch die zahlreichen, sich aus unterschiedlichen Disziplinen und oftmals auch Unternehmen zusammensetzenden Beteiligten hängt das Ergebnis eines Planungsvorhabens ganz entscheidend von einer erfolgreichen, standortübergreifenden Integration aller Mitwirkenden ab. Dieser Eigenschaft müssen auch die verwendeten Werkzeuge Rechnung tragen, um auf diese Weise Synergieeffekte bestmöglich zu nutzen und eine hohe Planungsqualität und -sicherheit zu gewährleisten.

Die Montage wird auch in Zukunft eine zentrale Bedeutung für die Produktivität und damit den Markterfolg eines Unternehmens haben. Oftmals findet erst hier eine weitgehende Anpassung des Produktes an die Bedürfnisse des Kunden statt. Mit steigender Komplexität zeitgemäßer industrieller Montagesysteme und wachsendem Kostendruck erfordert dieser Fertigungsschritt ein rechnerunterstütztes Planungssystem, mittels welchem zukünftige, reale Montagesysteme vorab virtuell in einem Rechner entworfen werden können. Die wesentlichen Aufgaben der Planungssysteme stellen Modellierung,

Simulation und Visualisierung dar, da nur durch diese eine Aussage über die "wirklichen" Eigenschaften eines Montagesystems bereits in der Planungsphase getroffen werden kann.

Vor dem Hintergrund der Erhöhung der Stückzahl- und Variantenflexibilität und der Forderung nach einer besseren Beherrschung des Investitionsrisikos sowie nach schneller Änderungsfähigkeit bei möglichst geringen Kosten spielen modulare Montagesysteme eine entscheidende Rolle. Daher konzentriert sich die vorliegende Arbeit in einem ersten Schwerpunkt auf die Entwicklung einer entsprechenden Engineering-Umgebung. Hierzu werden die Nutzungsmöglichkeiten anerkannter Planungswerkzeuge in einem integrierten Ansatz zur Planung modularer Montagesysteme erweitert. Ziel dieses Ansatzes ist die Entwicklung von Referenzbausteinen als „Entwurfsmuster“ oder „Pattern“ zur generalisierten Beschreibung von Modellen, so dass spezifische dreidimensionale Modelle modularer Systemkomponenten automatisch generiert und mit einer entsprechenden Simulationsumgebung verknüpft und visualisiert werden können. Wesentlich sind dabei die Konfigurierbarkeit der Modelle und die durchgängige Informationsbereitstellung für den Planenden. Eine wesentliche Aufgabe stellt in diesem Zusammenhang vor allem die Gestaltung manueller Montagearbeitsplätze dar, welche meist an den Materialfluss der gesamten Montageeinheit gekoppelt sind. Im Vordergrund stehen hierbei vor allem ergonomische Verbesserungspotenziale durch den Einsatz von Virtual Manufacturing-Software.

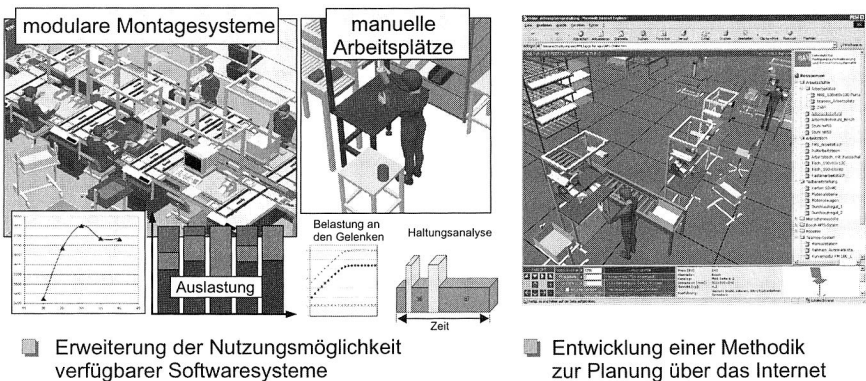


Bild 1: Lösungsansätze zur Planung und Gestaltung von Montagesystemen in einer dreidimensionalen Umgebung

Mit den sich ständig weiterentwickelnden Simulationstechniken stehen dabei wichtige Hilfsmittel zur Realisierung neuer Planungsmethoden zur Verfügung. Hervorzuheben ist in diesem Kontext beispielsweise die Entwicklung geografisch verteilter, internetbasierter Methoden zur Produktionsplanung. Über das mittlerweile allgegenwärtige Internet kann so ein leistungsfähiges, visuelles 3D-Interface zur Modellwelt des Computers an prinzipiell beliebigen Orten gleichzeitig verschiedenen Teilnehmern bereitgestellt wer-

den. Dies ermöglicht eine kollaborative, interdisziplinäre Planung und Evaluierung von Produktionssystemen und -anlagen. Vor diesem Hintergrund beschäftigt sich ein weiterer Schwerpunkt der Arbeit mit der Entwicklung einer virtuellen Engineering-Umgebung im Internet. Ziel der Arbeit ist es, webbasierte Softwareprototypen zur Planung und Gestaltung von Montagesystemen zu entwickeln und auf diese Weise eine verteilte kollaborative Planung zu ermöglichen. Zusammenfassend werden die Lösungsansätze zur Planung und Gestaltung von Montagesystemen in einer dreidimensionalen Umgebung in Bild 1 dargestellt.

Aufbau der Arbeit

Die Arbeit beginnt mit einer allgemeinen Darstellung unterschiedlicher Planungsaspekte bezüglich Montagesystemen in Kapitel 2. Insbesondere wird in diesem Abschnitt die Übersicht zum Stand der Technik unterschiedlicher Planungsmethoden und -werkzeuge sowie rechnerintegrierter Planungsansätze gegeben. Am Ende des Kapitels werden Anforderungen und Lösungsansätze zur Verbesserung des Planungsprozesses vorgestellt.

Ein Lösungsansatz zur rechnergestützten Planung modularer Montagesysteme in einer virtuellen Umgebung ist Thema des dritten Kapitels. Das Kapitel befasst sich mit der Erarbeitung eines integrierten Ansatzes zur dreidimensionalen Modellierung der Systemkomponenten sowie von Montagelinien mittels modularen Aufbaus durch die Erweiterung der Nutzungsmöglichkeit anerkannter Planungswerkzeuge. Kapitel 4 widmet sich der Entwicklung einer durchgängigen, simulationsgestützten Umgebung zur Optimierung manueller Montagearbeitsplätze, wobei das Augenmerk auf der Identifikation ergonomischer Optimierungspotenziale liegt.

Angeichts der Entwicklung und des Potentials moderner Internettechnologien ist von einer zunehmenden Veränderung des Erscheinungsbildes der Produktionsplanung auszugehen. Die Internettechnologien ermöglichen es, Entwicklungsumgebungen und -prozesse über verschiedene Standorte oder sogar über Unternehmensgrenzen hinweg zu verteilen. Kapitel 5 spezifiziert daher die für die Entwicklung einer virtuellen Engineering-Umgebung erforderlichen informationstechnischen Voraussetzungen.

Die Konzeption einer kollaborativen virtuellen Umgebung zur Planung von Montagesystemen über das Internet wird in Kapitel 6 dargestellt. Diese umfasst ein Konzept für das computergestützte Zusammenarbeiten sowie eine webbasierte Client-Server Architektur für die Montagesystemplanung und die Bereitstellung von entsprechenden Software-Werkzeugen. Zur Realisierung des Konzeptes wurde ein webbasiertes Planungswerkzeug für Montagesysteme namens „@WebPlan“ entwickelt, dessen verschiedene Module erläutert werden.

Die Entwicklung und Implementierung eines Prototypen zur kollaborativen Layoutplanung von Montagelinien in Webbrowsern wird in Kapitel 7 dargestellt. Im weiteren Verlauf der Arbeit wird in Kapitel 8 die Entwicklung eines Prototypen zur webbasierten

Montagearbeitsplatzgestaltung mit integrierter Ergonomieanalyse vorgestellt. Hierbei werden nicht nur räumliche, sondern auch zeitliche Aspekte zur Gestaltung von Montagearbeitsplätzen durch Integration eines webbasierten Werkzeugs zur Zeitermittlung nach der MTM-Methode berücksichtigt.

9 Zusammenfassung

Ausgangssituation für die vorliegende Arbeit ist die immer weiter zunehmende Komplexität in der Produktionsplanung aufgrund kürzer werdender Produktlebenszyklen innerhalb eines turbulenten Marktumfeldes. Um trotz schnellerer Modellwechsel bei gleichzeitig gestiegener Planungsgeschwindigkeit ein hohes Maß an Sicherheit bezüglich des Investitionsrisikos zu gewährleisten, bedarf es daher neuer Planungswerkzeuge. Darüber hinaus wächst die Bedeutung kollaborativer Ansätze zur Produktionsplanung aufgrund des verstärkten Einflusses neuer Informationstechnologien sowie zunehmend global verteilter Wertschöpfungsketten. In der Montage, dem letzten Schritt der Fertigung, verstärken sich diese Tendenzen, da vor allem hier die kundenindividuellen Produktausprägungen erzeugt werden.

Im Anschluss an eine Übersicht alternativer Ansätze zur Planung von Montagesystemen sowie einer näheren Betrachtung von Möglichkeiten zur Gewährleistung von mehr Flexibilität in der Montage erfolgte im ersten Schwerpunkt der Arbeit die Konzeption und Umsetzung eines integrierten rechnergestützten Ansatzes zur Planung modularer Montagesysteme in einer dreidimensionalen virtuellen Umgebung. Durch Erweiterung der Nutzungsmöglichkeit anerkannter Planungswerkzeuge wurden hierzu parametrisierbare Referenzbausteine zur generalisierten Beschreibung von dreidimensionalen Modellen modularer Montagesystemkomponenten entwickelt. Mit diesen lassen sich spezifische dreidimensionale Modelle automatisch generieren und gleichzeitig die Zuordnung zu den entsprechenden Simulationstypen sowie weiteren Informationen wie Preis und Gewicht hinterlegen. Von wesentlicher Bedeutung bei den entwickelten Referenzbausteinen sind die Konfigurierbarkeit der Modelle und die durchgängige Informationsbereitstellung. Anschließend kann mit den Referenzbausteinen die virtuelle Konfiguration modularer Montagelinien vorgenommen werden, wobei die Auswahl der Systemkomponenten für bestimmte Fälle durch Regeln und Algorithmen unterstützt wird. Mithilfe des hier vorgestellten Ansatzes ist es möglich, ein auf diese Weise generiertes dreidimensionales Modell der Montagelinie mit einer entsprechenden Simulationsumgebung hinsichtlich Materialfluss und Kosten zu verknüpfen.

Durch die Verwendung dieses Ansatzes kann der Planungsprozess extrem beschleunigt sowie die Wiederverwendbarkeit von Planungsergebnissen erhöht werden. Darüber hinaus unterstützt der Ansatz ein strukturiertes, effizientes Vorgehen bei der Modellierung der Systemkomponenten. Dreidimensionale Modelle von Montagelinien und die entsprechenden Simulationsmodelle lassen sich so innerhalb kürzester Zeit erstellen. Dadurch wird eine effiziente Beurteilung unterschiedlicher Konfigurationen bezüglich logistischer Kenngrößen und der Kosten-Leistungs-Verhältnisse der einzelnen Konfigurationen ermöglicht.

Einen wesentlichen Aspekt bei der Gestaltung eines Montagesystems stellt die Optimierung der Arbeitsplätze mit einem hohen Anteil manueller Tätigkeiten dar. In der vorliegenden Arbeit wurden in diesem Bereich anhand von Beispielen ergonomische Verbesserungspotenziale durch den Einsatz von Virtual Manufacturing-Software identifiziert.

ziert. Die Ergebnisse liefern wertvolle Erkenntnisse bezüglich ergonomischer und wirtschaftlicher Kenngrößen wie etwa Körperhaltungen, auftretende Kräfte und Momente an den Gelenken und Zykluszeit inklusive der entsprechenden MTM-Codes. Auf dieser Basis wurden mehrere Gestaltungsalternativen eines Prototypen virtuell erzeugt, simuliert und evaluiert und somit eine ergonomische Gestaltung des Arbeitsplatzes gewährleistet.

Die zunehmende Globalisierung und Virtualisierung und der damit einhergehende steigende Wettbewerbsdruck zwingen nahezu alle Unternehmen, ihre eigenen Strukturen fortwährend bezüglich ihrer Anpassungsfähigkeit und Flexibilität zu überprüfen. Unternehmen richten sich immer stärker international aus; infolgedessen arbeiten die Mitarbeiter zunehmend räumlich und zeitlich verteilt. Dieser Veränderung muss durch die Entwicklung neuartiger Planungsmethoden für die Endmontage, die eine Integration aller Planungsbeteiligten über verschiedene Standorte hinweg ermöglicht, Rechnung getragen werden. Basierend auf der Nutzung moderner Internettechnologien wurde hierzu in einem weiteren Schwerpunkt der Arbeit die virtuelle kollaborative Umgebung @WebPlan zur Planung von Montagesystemen geschaffen. Die prototypenhafte Realisierung erlaubt die Zusammenarbeit in Partnernetzwerken und bietet dem Anwender einen vielfachen, simultanen und verteilten Zugriff auf Planungsdaten in Verbindung mit der Darstellung dreidimensionaler Inhalte im Web-Browser.

Die verteilte Planungsumgebung beruht auf einer Web-basierten Client-Server Architektur, innerhalb welcher gegenwärtig der Internet Explorer von Microsoft als Client-Software zum Einsatz kommt. Als Gegenstelle fungiert ein Apache-Webserver zur Verwaltung und Auslieferung von Daten. @WebPlan stellt den geografisch beliebig verteilten Planungsbeteiligten 3D-Objekte, wie etwa Ressourcen in Form von Maschinen, Betriebsmitteln oder Einrichtungsgegenständen in Bibliotheken strukturiert zur Verfügung. Dabei können mehrere Planungsräume auf einem Server eingerichtet und von den Planungsbeteiligten mit Hilfe von Standard-Internettechnologien problemlos angesprochen werden. @WebPlan ermöglicht so eine verteilte und kollaborative Planung auf Basis eines gemeinsamen Planungsmodells. Die verwendeten Objekte liegen als VRML-3D-Objekte vor, welche sich aus einer Vielzahl gängiger CAD-Systeme importieren lassen. Als plattformunabhängiger und weltweit verbreiteter Industriestandard bieten VRML-Dateien mehrere Vorteile, wie zum Beispiel geringe Anforderungen an die Ausstattung der verwendeten Computer sowie erweiterte 3D-Modelle mit einem interaktiven und hochkomplexen Verhaltensmuster. Die in jedem Modul enthaltene, XML-basierte 3D-Objektbibliothek wurde in logische Gruppen strukturiert, um eine bessere Übersichtlichkeit zu gewährleisten. Von wesentlicher Bedeutung ist dabei die Möglichkeit, die Objektbibliotheken um externe 3D-Objekte zu erweitern. So können auch Ressourcen von Kunden bzw. Geschäftspartnern und Lieferanten in das System integriert und für den Planungsprozess verwendet werden.

Auf seinem gegenwärtigen Entwicklungsstand stellt das @WebPlan-Planungswerkzeug dem Anwender im ersten Schritt eines Planungsprojektes ein webbasiertes Modul zur

Layoutplanung von Montagelinien zur Verfügung. Verteilt agierende Planer können in einem gemeinsamen Modell Planungsobjekte anordnen und sofort mit den anderen Teilnehmern mögliche Varianten diskutieren. Bei einer Layoutplanung unterstützt der entwickelte Prototyp das schrittweise Vorgehen von der Block- zur Feinlayoutplanung. Zusätzlich zur Entwicklung eines Werkzeuges zur Layoutplanung wurde ein weiterer Prototyp zur Arbeitsplatzgestaltung über das Internet realisiert. Mit Hilfe des Prototypen lässt sich das Arbeitsplatzlayout auf mehreren, geografisch verteilten Gestaltungsräumen erstellen. Checklisten sowie Methoden zur Zeitermittlung ergänzen das grafisch dargestellte Layout um wesentliche ergonomische und wirtschaftliche Kenngrößen, wie z. B. Planzeiten nach der MTM-Methode.

Im Rahmen der durchgeführten Arbeit konnte ein wichtiger Beitrag zur Effizienzsteigerung von Planungsprozessen für Montagesysteme geleistet werden. Die beschriebene Methodik zeigt dabei die Potenziale einer Web-basierten kollaborativen Planungsumgebung hinsichtlich der Reduzierung von Planungszeiten und –kosten sowie einer Verringerung des Investitionsrisikos bei gleichzeitiger Erhöhung der Planungsflexibilität. Gegenüber bisher verfügbaren, konventionellen Systemen ist der hier entwickelte Ansatz darüber hinaus keinen räumlichen oder zeitlichen Grenzen unterworfen. Ein weiterer Vorteil liegt in der einheitlichen Benutzeroberfläche und dem erweiterbaren Funktionsumfang, da lediglich eine entsprechende Erweiterung des Microsoft Internet Explorers notwendig ist. Die gegenwärtige Beschränkung auf einen bestimmten – wenn auch weitverbreiteten – Browser ließe sich durch eine Realisierung des Systems mittels der plattform- und systemunabhängigen Programmiersprache Java beheben. Als zusätzliche Erweiterungsmöglichkeit kann das System um eine Option ergänzt werden, die sämtliche Mitglieder des Entwicklungsteams in Echtzeit über Änderungen am Modell informiert und mit der die Anwender immer gleichzeitig mit der aktuellsten Version der Daten arbeiten können.

Solution Approaches for Planning of Assembly Systems in Three-Dimensional Virtual Environments

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1 Introduction

The general trends towards shortened product life cycles, combined with continuously changing market environments have a decisive impact on the production planning processes. In order to master these turbulent situations, a constant further development of methods and planning tools is required. The planning tools which assist the planners to accelerate planning processes as well as to ensure the planning results before going to the implementation stage have been considered as vital requirements for a continued market success [163]. Furthermore, the production planning is also characterised by a shift from one-time projects to continuous planning processes, which consequently involves numerous management tasks [158]. Moreover, in the course of globalisation, the trend towards global corporate networks fosters the development of collaborative and participative planning methods in the distributed environments [54], [95], [137].

Against the background of various demands and influences in the industrial engineering activities, production planning in today's companies is a crucial factor for competing in a changing business environment. Modern software tools with simulation capabilities and improved visualisation play an important role in the production planning. Usually, these tools are based on solid models with feature-based data structures that store information related to all steps of the manufacturing processes. Consequently, design options can be created virtually in the computer and a fast evaluation of several alternatives can be performed in a relatively inexpensive manner. The weak points can also be identified in an early planning stage. Moreover, it allows a simultaneous engineering working environment, which accelerates the planning processes. However, virtualisation in all stages of planning processes may be difficult to overcome single-handedly for organisations due to few resources. Therefore, in the current competitive situation, a global cooperation among multiple parties like manufacturers, suppliers, vendors or planners is inevitable. In this context, intensive partnerships as well as concurrent engineering among related parties in the production development, particularly among geographically distributed teams, are increasing. In the face of this situation, there is a strong demand for solutions providing a common online environment for remote users to access distributed data and to accelerate information sharing.

The assembly represents the final part of the overall manufacturing process, in which a product gets its final form and functionality. As a final step in the manufacturing process, companies pay much attention to the adaption of their products to the customer's requirements. Therefore, in case of increasing complexity combined with the pressure to reduce time to market in this production stage, it is unavoidable to use computer aided planning tools, which can help the planner to design and simulate using "real" properties of assembly systems by means of virtual models. Thus, the expected results can be obtained already during the planning phase. This approach, called Virtual Manufacturing, allows in the broadest sense designing and building a product and its corresponding plant virtually with full simulation and visualisation. Special attention in this thesis will be given to the planning of modular assembly systems, which are mostly

used to comply with the increasing demand for flexible assembly systems. Due to their reconfigurability, such modular systems facilitate the adjustment and expansion of production volumes as well as the layout structure. Further attention will be paid to the improvement of manual workplaces in assembly systems. Due to the manual processes this is still mainly performed in the assembly.

The present work focuses on the development of an engineering environment for planning and designing assembly systems. The main emphasis lies on a conceptual approach to the planning of modular assembly systems. Particularly, it provides an integrated method for modelling modular components as well as their configurations. The goal is to develop new templates within existing software as reference patterns for the description of several modular component parameters. These templates help the users to set several parameter values and thus, an individual digital model is generated and associated information is created automatically. This modelling approaches should prepare a seamless integration between an assembly line model, generating by using this method, and the material flow simulation as well as cost aspects. In addition, improvement of manual workplaces in connection with human ergonomic considerations using the Virtual Manufacturing approach is a further focus.

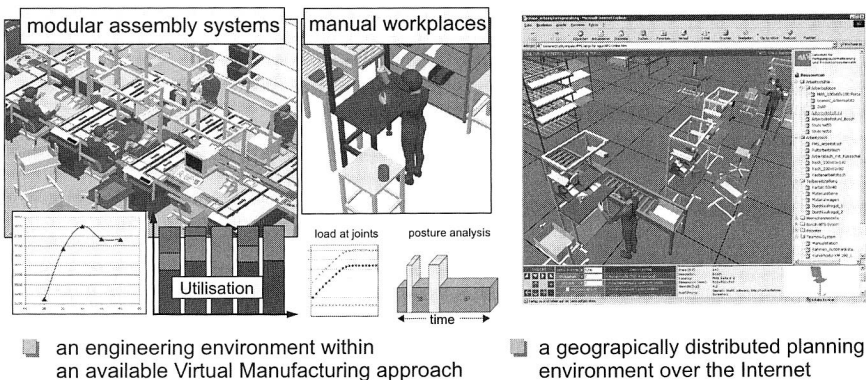


Figure 1: Approaches for planning of assembly systems in three-dimensional virtual environments

As mentioned previously, the trend towards globalisation also leads to the collaborative working environments among the parties involved. Working in multidisciplinary teams, information sharing and the exchange of ideas in different locations require adequate methods and tools. With the increasing ubiquity of the Internet and its corresponding technologies, several novel techniques have come up to develop collaborative tools for planning purposes, particularly in connection with specific technologies for displaying and exploring Web contents in three dimensions. In this context, further work in this dissertation deals with a solution approach for planning of assembly systems over the Internet. It includes the development of the geographically distributed planning virtual

environments, which is considered as a main focus in this dissertation. The virtual environments provide remote users with a multiple, simultaneous and distributed access to the project data including 3D layouts of assembly lines and manual workplace incorporating ergonomic considerations as well as a working time estimation method. Figure 1 summarises these solution approaches for planning of assembly systems in the three-dimensional virtual environments.

Outline of the thesis

This dissertation begins with a discussion on several planning issues in connection with assembly systems in Chapter 2. Particularly, the state of the art of several widely used planning methods, computer-integrated approaches and planning tools are some of the subject matters covered. At the end of this chapter, the deficiencies in the planning of assembly systems will be identified in accordance with today's technologies stands and the solution approaches to overcome these drawbacks are proposed.

Chapter 3 approaches the planning of modular assembly systems in a Virtual Manufacturing environment. This chapter focuses on developing an integrated approach for 3D modelling of system components as well as assembly lines with modular designs. The approach presented provides an accelerated modelling process for modular assembly systems, a seamless integration with corresponding simulations and an improved visualisation. Subsequently, the design of manual workplaces will be addressed in Chapter 4 and special attention will be paid to ergonomic considerations as well as human simulations in a three-dimensional virtual environment

The rapid development of emerging Internet technologies brings out an important impulse to apply their potential to production planning processes. These technologies are characterised by supporting teams or users in geographically dispersed locations and by enabling collaboration and leveraging of information from a Virtual Manufacturing model. Therefore, Chapter 5 discusses related technologies providing computer support for collaborative work over the Internet.

A concept of planning and designing of assembly systems in the collaborative virtual environments over the Internet is presented in Chapter 6. It contains a concept of collaborative works, a Web-based collaborative architecture for assembly systems planning and software tools needed for the realisation of the concept. A Web-based planning tool for assembly systems, called “@WebPlan”, which contains different application modules is introduced at the end of this chapter.

The development and realisation of a Web-based prototype for collaborative layout planning of assembly lines is addressed in Chapter 7. In the course of a further software development, a Web-based prototype for workplace layout design incorporating ergonomic analyses is presented in Chapter 8. The prototype includes a Web-based tool for a predetermined time system according to the MTM-method.

2 State of the Art in the Planning of Assembly Systems

This chapter begins with a discussion on several planning issues in terms of assembly systems. Particularly, they include issues relating to the flexibility in the assembly systems and the usage of modular designs. Another issue to be considered is the ergonomics for designing manual assembly workplaces. Based on these issues, an integrated planning approach for the planning of modular assembly systems and an ergonomic simulation in a Virtual Manufacturing environment will be developed later on.

Subsequently, Chapter 2 gives an overview of several methods and computer-integrated approaches for planning the assembly systems. Numerous planning tools have been released in order to implement the methods and approaches. In addition, several institutions, researchers and commercial software providers are also involved in development of these tools. On the basis of available solutions and determination of the communication requirements in the planning of assembly systems, an alternative solution approach for virtual and collaborative planning of the assembly systems over the Internet has been proposed at the end of this chapter.

2.1 Planning Issues

The Webster's dictionary defines assembly as 1) the fitting together of manufactured parts into a complete machine, structure or unit of a machine, or 2) parts are joined together to form a unit. Also the operations that are indirectly necessary to fit parts together are considered as an "assembly". According to the German DIN¹ 8593 standard, assembly means to compose together parts and/or group of parts to create a product or to configure the grouping of products in the manufacturing. The term "assembly processes" includes all activities required that to join parts or sub-assemblies with one or several parts or other sub-assemblies. This activity generally refers rather to discrete product manufacturing than to continuous processing. This also includes all kinds of workpiece handling processes according to the VDI-Guideline² 2860/1. The assembly processes can be classified according to their activity features as presented in Figure 2. They cover all kinds of the adjusting and the controlling processes, as well as the carrying out of auxiliary functions such as cleaning, burring, etc.

An assembly is a part of the manufacturing process, in which a product obtains its final form and functionality. During the final step in the manufacturing process, most of the assembly processes are performed rather manually than automatically. Even for manufacturing high technology products, such as mobile telephones, the processes in the beginning stage are characterised by a high-automated electronic production, e.g. high-speed automatic placement machines with automatic reflow soldering processes for assembling printed boards. In contrast, manual work is still dominant in the end phase

¹ DIN stands for *Deutsches Institut für Normung* (the German Standard Institute)

² VDI-Guideline is set of technical regulations from the *Verein Deutscher Ingenieure* (Association of German Engineers)

(*back-end assembly*) due to the highly flexible product variants. The main drawback of manual assembly processes, particularly in the industrial countries, is the high labour cost. It varies between 50% and 75% of the total labour cost for manufacturing the product [9]. Optimisation of the assembly process therefore plays a very important role in this context. In the sixties, this was mainly achieved by optimising the manual assembly operations. Taylorism is a kind of rationalisation that mainly focussed on the optimisation of the manual assembly operations. Thus, the assembly times were recorded and evaluated, and then the motions of the operator were analysed. In the seventies, automation of the assembly process was seen as a solution to the increasing labour cost. These automation projects did not lead to the expected result because of several technical problems that had to be overcome. Subsequently, a more promising way to improve the assembly process was to optimise the product design for the assembly.

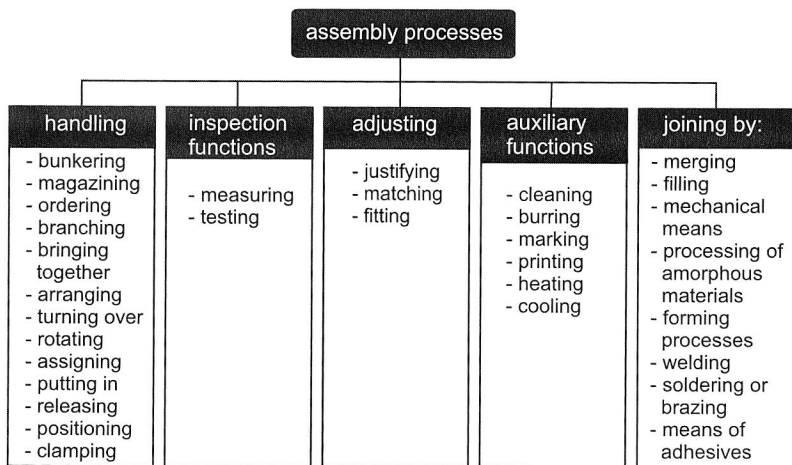


Figure 2: The grouping of assembly processes³ [83], [118], [143]

The assembly of products is facing a continuous cost pressure, due to the low labour costs in the developing countries. On the other hand, automation of the assembly processes is possible only if the required investment pays off within a few years. It must be economically justifiable, and is not seen as an expansion of the factory's know-how and capabilities. Apart from the reduction of the assembly costs that increase the competitiveness of the product, there are other advantages in automating the assembly process. The demand for high quality products has become very important. If automation is carried out correctly, the quality of the products can be guaranteed, by assuring almost zero defective assembly processes. The human worker is often seen as an ideal flexible

³ The term of assembly processes are an English translation of the German DIN 8593 standard for joining processes and VDI-Guideline 2860/1 for handling processes.

assembly machine, but his production rate is neither constant, nor of constant quality. Many small and medium sized companies put a lot of efforts in assembly, but they are not suited for a high degree of automation, because production volumes of their products are too low, or the products have a life cycle that is too short to justify dedicated automation. Thus, manual or partially automated and up to hybrid assembly systems are more favourable.

In connection with the present work, several planning issues of the assembly systems will be overviewed in the following sections. They include issues, which are related to the selection of the assembly processes and the efficiency of assembly systems. Flexibility in assembly system is another issue. In this context, the modular designs have been revealed as an appropriate solution for increasing assembly flexibility. A further issue to be considered is ergonomics in the manual as well as partially automated workplaces. The methodologies for planning of the assembly system as well as numerous developed planning tools will be addressed in a separate section in this chapter.

2.1.1 Selection of the Assembly Processes

The current state of the assembly technology covers a wide spectrum of capabilities and practises across many countries and includes a mix of manual and automated processes, which is often found in partially automated assembly lines. This choice of automated vs. manual processes depends on multiple factors such as cost, complexity, schedule, safety, rate, labour agreement, etc. Sometimes automation is chosen to provide a repeatable process or to get people out of the process for health and safety reasons. However, automation is not useful in many cases. For example, the results of manual assembly in the aircraft manufacture are more than adequate. Therefore, automated processes in this area only increase capital investment expenses and create additional problems.

One of the most successful applications of highly automated assemblies can be found in the area of electronics production, including final assembly of microelectronic devices and printed circuit cards, e.g. the use of pick-and-place machines for electronic component insertion. Other examples for automated assembly processes include a wide range of high volume automotive, consumer and office products.

In contrast to the automated processes, the manual assembly processes are dominant for low-volume or mixed-technology products, where the assembly processes are highly variable or not consistently predictable or controllable, or where proper assembly relies on individual experiences and proficiency. For instance, the electromechanical assembly, e.g. wiring harness routing, optics frame mounting or sensor integration is predominantly manual.

2.1.2 Efficiency of the Assembly Systems

The efficiency of the assembly systems or workplaces is given by the percentage of the primary operations time compared to the total assembly time [83]. In this context, the

primary operations refer to the operations that directly add value to the product, in particular the processes of joining parts. The total assembly time consists of primary and secondary operations. The secondary operations correspond to the operations that have to be executed in order to perform the primary operations, without any contribution to the product's added value. These include the transport of parts to the joining positions, parts preparation, storage, etc.

The efficiency of assembly systems is considered to be a quantitative planning criterion for the improvement of a new assembly system or for rationalisation of an existing one. The reduction of primary operations can be achieved by a simplification of the joining processes, e.g. by providing joining aid or looser fit. The optimisation and rationalisation of assembly systems refers to the reduction of the secondary operations. They can be achieved by handling as well as motion simplifications or by reducing or eliminating parts preparations. The application of high assembly techniques and full-automated assembly increases the assembly systems' efficiency. It can also be achieved by motion simplifications or by improving workplaces layout design according to motion economy principles for the manual assembly systems.

2.1.3 Flexibility in Assembly Systems

Flexibility is needed in assembly systems because product life cycles are getting shorter, lot size is getting smaller and the number of variants is increasing. According to [152], flexibility can be classified into capacity and capability flexibility. The latter refers to the system's ability to react to changing market demands in terms of the product variants that are demanded, whereas the capacity flexibility of an assembly system is its ability to react to changing market demands in terms of quantities asked for. In general, the demand for a product starts low, increases and falls down again when the product's economic life cycle ends. The third type of change to which the assembly system must be able to react are the internal disturbances which occur during the assembly and compliance of the system's operation. Therefore, another type of flexibility required by the flexible assembly system is the ability to deal with errors.

Thus, today's requirement for the assembly systems is the ability to adapt to varying product life-cycle volumes, product variants and new products within the same system. This means that a system must have static flexibility, i.e. layout modifications and reconfigurability, and dynamic flexibility, such as the use of information technology [60].

The design task of flexible assembly systems is very challenging. Assembly system design and selection involves a number of related subjects, including the flexibility needed for future engineering changes or a capacity adjustment and space strategy. Faster production system design and faster ramp-up processes are needed more than ever because the time-to-market has become more critical. Simulation and Virtual Manufacturing tools are available to reduce the time needed in the design steps. These tools also hasten the production ramp-up, because the operator knows the planned system better and can study the new system before anything is installed on the factory flow.

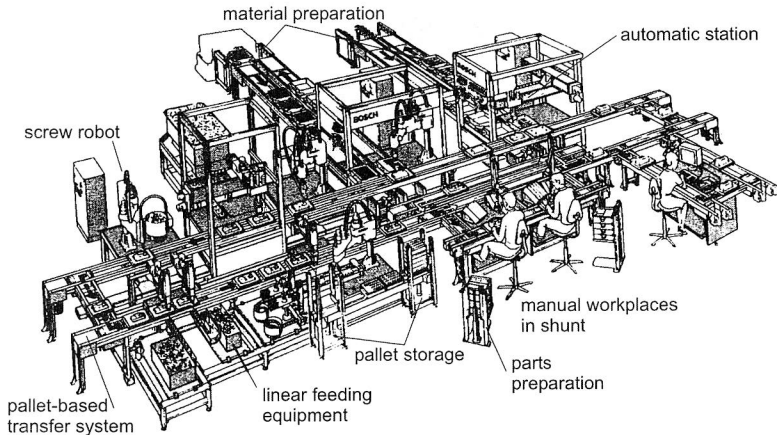


Figure 3: A flexible assembly line using modular designs (Courtesy of Bosch Rexroth Corp.)

Flexible assembly lines are traditionally based on the flow assembly principle [129]. According to this principle, all assembly operations have been assigned to several workstations and allow the application of different automatic stations in an assembly line. Flexible assembly lines can contain both, automatic as well as manual workstations. Several stations are connected by means of transportation systems and function as a central system element.

The modular designs are increasingly used for the flexible assembly systems [45]. The system components of modular assembly system consist of the base units, the transfer units, and the working unit, e.g. industrial robotic, power screwdriver and control units. Due to the modular construction, a flexible assembly line can be built up. This is composed by several automatic and manual workstations, which are linked to a central transport system. The flexibility of such a system depends on the convertibility of transport systems, easy exchangeable workstations, as well as the extensibility of the entire system. Figure 3 shows a flexible assembly line with a modular construction system.

In connection with the flexibility and the usage of modular designs in assembly systems, Chapter 3 will discuss an integrated planning approach for modular assembly systems in a Virtual Manufacturing environment by expanding the application area of an available software tool. This chapter focuses on developing an integrated approach for a 3D modelling of the system components as well as assembly lines with modular designs.

2.1.4 Ergonomics

The practice of fitting the workplace to the capabilities of the human worker is one of the planning issues for assembly systems, particularly in the manual workplaces. Ergonomics apply knowledge from biomechanics, physiology, psychology and engineering to the

design of tasks, work organization, work environment, workplaces and tools. Incorporating good ergonomic principles during the design stage for manual and partially automated assembly workplaces is considered to be an important factor due to the increasing process efficiency and the improvement of worker safety and motivation.

Methods and tools for the design of the workplaces with ergonomic considerations have been developed for many years. One of the oldest methods is sketches and hand drawing for workplace design. In contrast to the sketches method, human figure templates have been used as an improved method. Introducing a computer tool for the design of a workplace begins with the application of a 2D-CAD program. Without rendering capabilities, this tool provides human models with ergonomics analyses concerning working postures and reach ability as well as an identification of the potential health risks. A further advanced method uses computer-generated three-dimensional human models on a CAD software system. Some of the human models are the Jack model from EDS-PLM [10], RAMSIS from Techmath [139], ANTHROPOS from IST GmbH [100], and the human model from SAMMIE CAD software tool [126]. Several computer aided planning software embed these human models in order to add their ergonomic capabilities. They exist in planning software tools such Ergomas from Delmia solution and eM-Human from Tecnomatix. The advantage of this method is the complex analysis of the human factor in the working systems with support of the human simulation during performing the assembly tasks. In connection with ergonomics considerations and simulation support, Chapter 4 deals with the application of a Virtual Manufacturing approach in order to improve manual workplaces.

2.2 General Planning Methodology

The VDI guideline 2221 [121] and REFA planning methodology [130] are known as general methodologies for system planning. In terms of system engineering, VDI methodology breaks down the task definition of the complex system into less complex partial systems. The systematic design procedures consist of several operational stages, including clarifying the task, conceptual design, embodiment design and detail design.

A non-profit organisation for the work-study, industrial organisation and corporate development, called REFA⁴, has developed another methodology, which is a collection of methods and tools to be applied in order to obtain an improved work organisation. The methods focus on work design (work systems and work processes) and on the collection and evaluation of company data. REFA methods enable the applicants to deal with work organisation and process management systematically in an approach, which comprises many aspects. Figure 4 shows the REFA's planning methodology. This methodology comprises six levels, which systematically describe the planning and the design of work systems. In addition, a following planning level can be preceded, if the previous level has given a planning result. Each of these levels is supported by suitable tools and

⁴ REFA is an abbreviation of the German, *Reichsausschuss für Arbeitsstudien*

methods. According to the present work, both methodologies can be applied as a systematic model, even though they have not been directly considered in the planning of assembly systems.

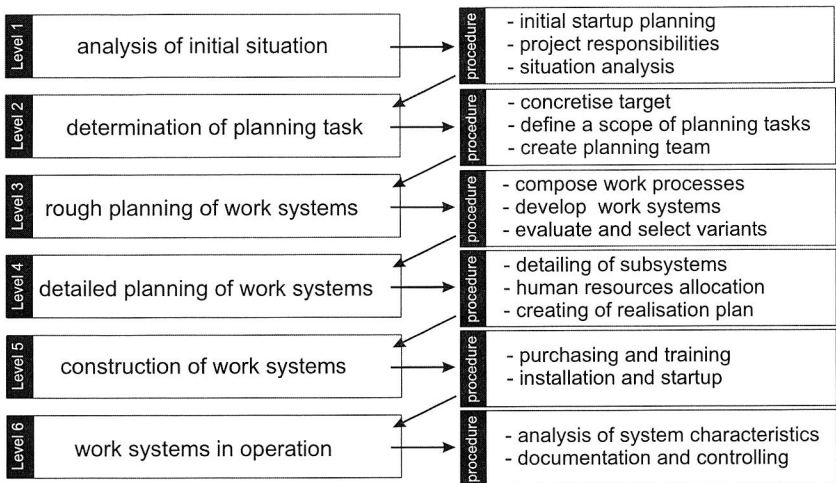


Figure 4: Planning method according to REFA (simplified)[130]

2.3 Methods for Planning of Assembly Systems

Several established methods for the planning of assembly systems known from literature are presented in this section. They include planning methods according to Bullinger [29], Deutschländer [41], Grob and Haffner [57] and Lotter [83]. The structure of these planning methods follows two kinds of procedures, namely, one is either organised with regard to the planning contents (e.g. process planning, system planning) or one organised with regard to the level of detail (e.g. rough and detailed planning). There is no strict sequential procedure for implementing every planning stage, but various iterative processes have to be carried out in order to obtain an improved result. The requirement of parallelisation of product engineering and assembly planning has been considered by using these planning methods, but it is not followed by an implementation concept. Thus, the coordination between product engineer and system planner should be accomplished by means of organisational measures.

2.3.1 Bullinger's Method

Bullinger has developed a detailed guideline for systematic assembly planning, which involves project organisation (Figure 5) [29]. He describes a structured approach for the optimal sequences during the planning of assembly systems. This systematic method has been developed based on a long experience in planning and designing of assembly

systems. The planning activities begin with a planning concept, which defines the goal and creates solution principles. Then, it is followed by an assembly sequence planning, in which the product structuring is carried out and the assembly sequences are acquired. In the next sequence the assembly system is designed. It consists of the assignment of assembly tasks to workstations in a configuration. Thus, design of material flows and system layout are performed in this stage. To ensure the planning result, the assembly system can be simulated. Furthermore, the design of each station has been detailed. Finally, the assembly planning ends with the realisation and operation, where controlling and rationalisation measures can be implemented.

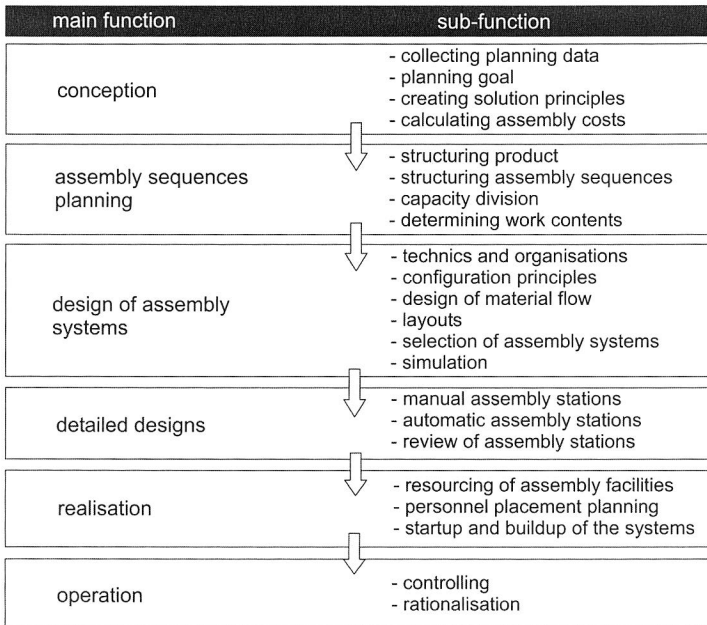


Figure 5: Systematic assembly planning according to Bullinger (simplified)[29]

2.3.2 Deutschländer's Method

Deutschländer [41] set a comprehensive collection for the assembly planning, which is subdivided into seven main functions. These functions encompass analysis, design, documentation, concept development, economic evaluation, detailing and implementation. Deutschländer accents that the planning processes deliver no optimal result. Thus the improvement can be achieved by means of iteration of overall processes.

Deutschländer's planning systematic provides a computer support. The main components of his procedure model cover system definition, assembly sequence planning, finding solutions as well as concretisation and solution improvement. The planning re-

sult according to this method is a designed model of an assembly system, which comprises the task as well as the assembly facilities.

2.3.3 Grob and Haffner's Method

Grob and Haffner [57] have developed a planning system for configuration of work systems for Siemens. The system emerges from the company's experience of numerous work structuring projects. Based on the various experiences in the project work, the planning process is conducted by certain planning stages. The outcome is a detailed planning process, which presents the structured procedures point by point. First, a given situation is analysed by paying attention to the weak points. The following step identifies the goals, formulates the task and determines the criteria, which are monetarily problematic (e.g. flexibility in respect of multiple parts). Subsequently, various solutions are taken into consideration and evaluated. These stages will be followed by presentation of the planning result and making a decision. Finally, the chosen solution is implemented and analysed with regard to its success. This method does not take into account the integration of the planner's activities to the activities of the product engineering

2.3.4 Lotter's Method

Lotter has developed a praxis-oriented assembly planning method (Figure 6), especially for the light assembly products such as electronic goods. He accents that there are no planning methods, which can be accepted generally, because different products need different procedures. His planning method starts with a requirement list. Subsequently, the product is being analysed in order to identify the unnecessary parts in its assembly processes. The goal is to create products that are functionally efficient and easily to be assembled. Assembly sequence analysis requires precedence relationships between product components and derived individual assembly, on the one hand, and their function analyses, on the other hand.

The next planning stage deals with cycle time calculation, layout planning and personal requirement planning. The investment calculation in the end stage of the planning method points out the economic aspects of the selected variant and provides information about the optimal solution. Lotter also mentions the necessity of the integration of product engineering with planning.

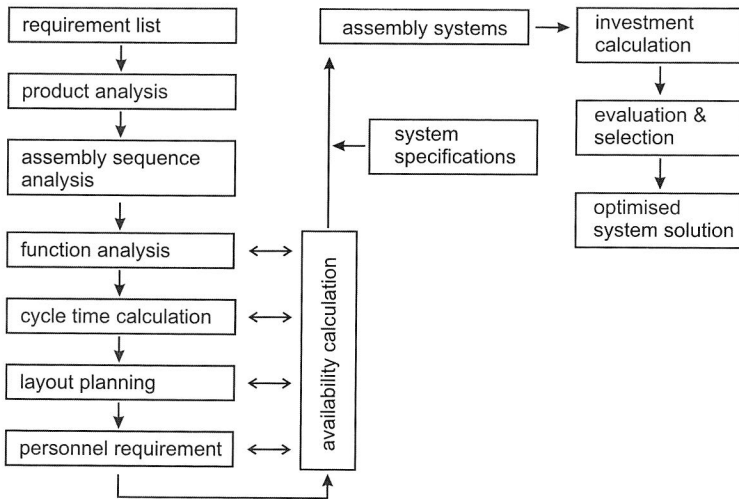


Figure 6: Assembly planning method according to Lotter (simplified)[82]

2.4 Computer Integrated Approach for Planning of Assembly Systems

A computer integrated approach for the planning of the assembly systems has the goal to provide a data exchange in the development process between product engineering and assembly systems planning in the earliest stage. For this purpose, the approach allows both divisions to access the same data model. The moment the designer confirms the product's rough geometry, the planner can begin to plan and design the corresponding assembly systems. The opposite of the previous situation occurs when the planning problems can already be considered from the assembly point of view during the product design phase.

2.4.1 A Systematic Structuring for a Computer Integrated Approach

A systematic integrated approach for assembly system planning consists of several components, which provide the functionality for different planning tasks. A basic aspect of this integrated computer-aided environment, which designs, simulates and optimises assembly lines and stations, is a data model. This model specifies the assembly systems with all their systematically aspects. The activity begins with a product structure, which will build up an assembly structure. The assembly process graph is based on a product structure. It includes all assembly sequences and tasks, which are required to assemble the product. The resources e.g. facilities and workers, which are essential to accomplish the assembly tasks, complete this integrated approach. The data model consists of product, process and resource data models and is stored in a common da-

tabase. The data model integration, which is a fundamental requirement for a computer-integrated approach, supports links to a wide variety of other individual planning tasks. Thus, the information generated by certain planning tasks is accessible and logically linked to other ones.

According to [45], the requirement of a computer-integrated approach for assembly system planning is a systematic structuring of data and functions (see Figure 7). The fields of functions, such as product engineering, simulation and planning are associated with product, process and assembly system models as well as the corresponding software tools. In addition, the model hierarchy is another essential structuring criteria. On the basis of this hierarchy, three levels of detail can be established, namely line, station and component level.

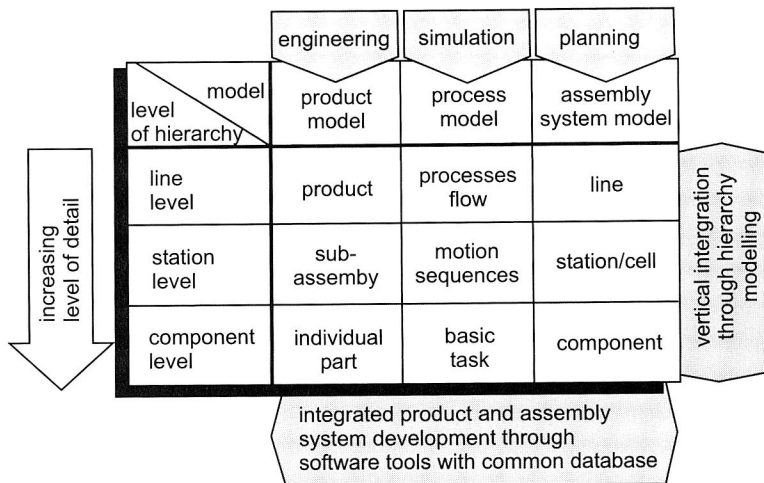


Figure 7: A systematic structuring of a computer integrated approach for assembly system planning [45]

2.4.2 Planning Tasks and Data Model

Various planning tasks, particularly for planning of manual and partially automated assembly systems will be discussed in this section. A systematic assembly planning approach for this purpose normally begins with the product. The planning task in this stage offers the possibility to represent the complete product structure by using main modules, modules, sub-modules and parts with any desired level of detail. A viewing tool should support the planning task in order to digitally mock up a complete design. In addition to digital mock-up, a target costing can be performed in order to estimate all cost factor as well as labour-force and space requirement at the beginning of the planning stage. The assembly sequence planning is the next planning task. Normally, it is based on the

product structure. In this stage, the links between each process step and the corresponding manufacturing resources can be built. Thus, assembly operations and the product-resource data links are stored in a shared product, process and resource data model. The determination of the assembly time for each operation is a further planning task and a predetermined time system e.g. Method Time Measurement (MTM), can be used to analyse the working time information. The required time for all assembly sequences can be accumulated from each assembly operation time. In this stage, the planning task consists of the distribution of the work content among a set of workstations within certain configuration.

The next stage involves the defining of the assembly line layout and of the material flow model. Material flow simulations are used to verify line performance, throughput, resource utilisation and bottleneck analysis. A detailed workplace design is developed in the following steps. Tasks performed in this phase include layout of workplaces, selection, dimensioning and arrangement of operating materials. Manual workplaces can be justified by ergonomic analyses and worker simulation during working. Moreover, workplace costs analysis can be performed in the end of this stage. Figure 8 depicts the systematic planning tasks for assembly systems in a computer-integrated approach. They include several synthesis tasks (e.g. layout planning, workplace design) and analysis tasks (e.g. material flow and worker simulation). Furthermore, a data model that provides the storage and management of all product, process, and resource information ensures the integration between several planning tasks.

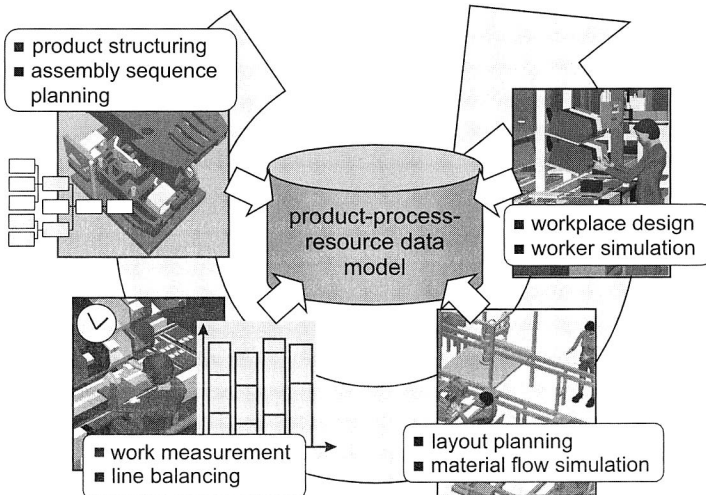


Figure 8: Several assembly planning tasks and a data model [50].

2.4.3 Commercial Approaches

There are several commercial software companies, which offer solutions for production planning including the planning of the assembly systems. These solutions allow manufacturers to market their products quickly. Moreover, they reduce production costs and encourage innovations at the same time. An integrated, synthetic manufacturing environment exercised to enhance all levels of decision and control in product and process design, process planning, production planning, and shop floor control is the current state of the art in this area [14]. It includes terms such as Virtual Manufacturing [75], [123], Digital Manufacturing [97] and Digital Factory [12], [136].

The term “Digital Manufacturing”, for instance, emphasizes the process planning using 3D CAD models and associated information for visualising, modelling and simulating purposes. A Digital Manufacturing environment revolves around a product, process and resource data model that manages the information and illustrates the way the product, process and resource information should be shared across activities. Obtaining highly accurate and real time 3D simulations to rapidly evaluate and to prove manufacturing concepts is the main goal of this approach. Delmia (www.delmia.com) and UGS (www.ugs.com) are two of the leading providers of digital manufacturing software.

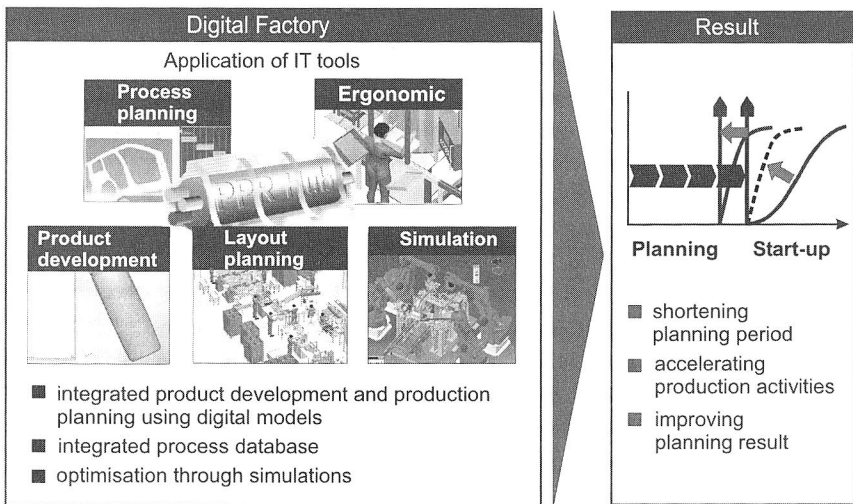


Figure 9: Concept of Digital Factory

Recently, several researchers [159], [162] and software providers have used the term “Digital factory” to represent an integrated and synthetic manufacturing environment. In essence, the Digital Factory concept (see Figure 9) applies information technology tools to the optimisation of manufacturing plants. It builds the basic communication platform in order to create planning alternatives, which already eliminate the planning mistakes in

an early phase. Overall, factory processes have to be virtually modelled, tested, simulated and optimised using digital models before being carried out and installed in reality. The use of integrated product development, production planning and integrated process database enables this concept to shorten planning times, accelerate production activities as well as to improve the planning result. The car manufacturer Daimler-Chrysler argues that the constant application of the digital factory could result in timesaving of up to 30 percent in the factory start-up and operation [12].

The following section gives an overview of commercial approaches for the planning of assembly systems. These commercial software companies use the same Digital Manufacturing concept, which utilises 3D CAD models and associated information for planning and simulating purposes. They also have a similar data model that manages the product, process and resource information and each of them has a unique name.

Delmia's Approach

The commercial software company Delmia provides a suite of software solutions to support manufacturing processes, which have to be planned, detailed and simulated throughout the manufacturing engineering cycle. The software solutions are built around an open Product, Process and Resource model (PPR), which enable persistent storage and management of the information required for the production planning. The PPR data model enables a seamless integration with various planning tasks and thus the production planning cycles can be dramatically reduced. Figure 10 shows various planning tasks for production and assembly systems according to the Delmia's approach. This approach provides a structured planning method, which is utilised from the conceptual product design, process and resource planning up to the system planning stage for manufacturing scenarios mature.

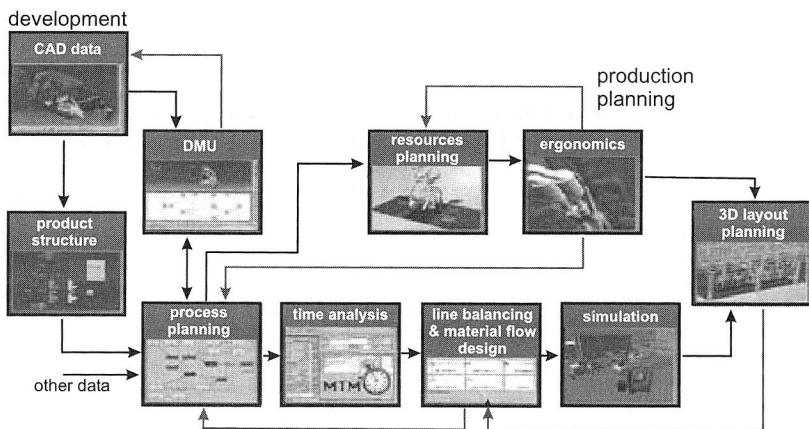


Figure 10: Various tasks for assembly planning according to the Delmia's approach [12]

Delmia Process Engineer (former Ergoplan) is an integrated planning tool, which has various modules that enable it to perform several planning tasks. They include product evaluation and Digital Mock-up (DMU), process and resource planning, time analyses, line balancing, cost analyses and layout planning. In addition, Delmia Human is an add-on module for ergonomics and worker process analysis in the design phase. Another software tool, called Delmia QUEST, provides a process flow simulation and Delmia Robotics (former IGRIP) enables robot programming as well as workcell layout and simulations.

Tecnomatix's Approach

Tecnomatix, another competitor in this area, also provides a suite of planning tools, called eMPower, which provides several solutions for planning, detailing and simulation throughout the manufacturing process lifecycle. Analogue to Delmia's approach, eM-Power has also a unique data model, called e-BOP (electronic Bills of Processes), which is stored in the eMServer. The eBOP Manager enables access to the eMServers so that collaboration and tracking several projects regardless of where they are located can be performed. The latest technology of eBOP manager enables incorporating real-time, dynamic streaming and XML (Extended Markup Language) in order to interact with an integrated database and exchange 3D production information over the Web [76]

A suite of planning tools eMPower functions as a line of Manufacturing Process Management (MPM) solutions and addresses "how" a product has to be manufactured and provides the link between product design systems that address "what" has to be manufactured, and shop-floor execution systems that address "when and where" information. EM-Planner as an individual eMPower product is responsible for planning, analysing and managing manufacturing processes throughout the enterprise. EM-Plan can perform design, simulation and optimisation of production systems and processes. Another software tool, called eM-Workplace NT, enables planning and designing of complex assembly line facilities and workplaces. This tool supports a structured process from block layout, through line planning to detailed design and optimisation of the individual workplaces. In addition to the assembly facilities planning, manual assembly design and analysis can be conducted by using eM-Human. The eM-Human provides a wide range of 3D virtual human models that allow accurate simulation of manual tasks, as well as the analysis of ergonomics and assembly time.

UGS's Approach

E-factory is a complete digital manufacturing solution from UGS system that helps companies to quickly identify the best strategies for boosting productivity and lowering cost. E-factory has a data management system, called Teamcenter, which associates product data with process, resource and plant data. Users can visualise and collaborate on this associative data, taking advantage of powerful workflow control and change management functionality. Thus, Teamcenter greatly increases the value of the information,

transforming it into structured knowledge and extending its reach throughout the product lifecycle.

UGS's approach covers several manufacturing solutions. They include a solution to support all activities for manufacturing parts, process planning, resource management, plant optimisation, human performance and quality planning. In order to provide capabilities in the process planning and plant optimisation, E-factory leverages Tecnomatix eM-Power software. By combining their complementary strengths, both software providers offer companies an extensive and a proven set of solutions for digital manufacturing.

2.4.4 Research Approaches

Seliger's Method/MOSYS

Seliger [140] has developed an integrated assembly planning method that focuses on the operational organisation. The method assumes that the product is already designed. The Seliger's method describes at first the assembly processes by means of the standard processes like handling, joining, conveying and testing. Each process requires the corresponding equipments in order to carry out an assembly operation. The assembly lines are planned according to the assembly sequences, which are based on the bills of materials and precedence diagrams.

The planning tool called MOSYS (stands for the German "*Modellierungssystem*") supports this method. It facilitates the layout planning for the assembly cells and in doing so it focuses on the technical feasibility of the assembly tasks. It also provides approaches to the cost analyses. However, the evaluation criteria or the technical premises are not described in detail.

Schuster's Method/COSEM

Schuster [138] has developed the planning tool COSEM (stands for the German "*Computergestützte Strukturierte Entwicklung von Montagesystemen*"). His planning system accents the planning of the flexible automated assembly lines. Through organisational integration as well as tasks and computer integration, Schuster's method creates the premises for a simultaneous planning tool and consequently the integration of designing and assembly into the entire planning process. This method consists of three blocks, namely the preliminary assembly process planning, the rough and the fine planning of the assembly processes and systems. These planning stages are chronologically classified according to the design stages.

COSEM uses the 3D simulation system USIS for the visualisation of assembly systems. A database supports its data management system. An important aspect of this planning tool is simultaneous engineering support in product development and assembly planning. The first step of this planning system is determining the alternative assembly sequences and operations. This step considers the primary components of the automated

assembly systems such as grippers and workpiece carriers. Subsequently the process planning determines the alternative system structure by means of a 3D simulation. Based on the analysis of the system structure, the layout planning and evaluation of several scenarios can be performed with regard to the technical and economical criteria. The implementation of COSEM helps to support the various planning fields. This planning tool contains modules, such as components catalogue, planning of the assembly processes and systems, documentation and information as well as calculation of the investment costs module.

Planning Tool CosMonAut

Feldmann [44] has developed a method for seamless integration of computer-aided assembly planning. His method can be considered as a direct continuation of Schuster's method. The planning tool, called CosMonAut (stands for the German "*Computersystem zur Montage-Automatisierung*"), allows an integrated planning, which starts with the defining planning goal and ends with the supporting the operation of the planning result. The foundation of the method is an integrated data management and standardised data exchange. Thus, a specialised planning tool will support each planning task. The data of an individual planning step is an aggregate of product, resource and process data. The planning tool CosMonAut has a workflow system, which contains all assembly operations and their sequences in term of building blocks. The workflow has been developed by the 5-layer-method. The notation of workflow and symbols of graphic presentation are based on the VDI guideline 2860.

The required plant facilities can be selected from a central database, which contains numerous resource components with their technical data from different companies. In connection with the resource components in the database, Loferer [79] has enhanced the capabilities of this planning tool with supporting the procedure for selecting the resource components and the integration of the supplier's product catalogue. CosMonAut also supports the planner in creating several alternatives of the manufacturing concept and in using tools for time and cost analyses in order to carry out the evaluation of each alternative.

Aiming for the expansion of the CosMonAut capabilities, Cuiper [39] has developed his method for a seamless planning and controlling automated assembly operations. Several enhancements have been performed in order to match the system requirements. They include additional editors for the planning and analysis of the assembly process, which allows a graphic-interactive design of the Petri-net and the assignment of the control commands. An interface called CORBA allows the communication with simulated or real control components. The PPS-system has been implemented for data exchange. The task schedule can be transferred to this system. Thus, the planning data can be reused in the operation stage.

Ifab's Computerised Planning Tools

The Institute for Human and Industrial Engineering (ifab) at the University of Karlsruhe has developed since the 90's computerised planning tools for the assembly planning [25]. The goal is to support the whole assembly planning processes, from design for assembly up to ergonomic design of the workplace. The ifab's planning tools consist of several systematic modules. The first module is SIMONA (stands for the German "*Simulation in der Montage*"). It supports product manufacturability analysis. Another module, called RAMONA (stands for the German "*Rechnerunterstützung zur Arbeitsteilung in manuellen Montagesystemen*") supports the organisational planning of the manual assembly systems. Thus, planning scenarios can be analysed by using a discrete event simulation. The evaluation of planning alternatives is based on several parameters such as efficiency, output, lead-time, delivery dates and order balance. The DEMONA module has a relevant contribution to the improvement of the structure of assembly systems.

Ifab's planning tool EMMA (stands for the German "*Experte zur Gestaltung manueller Montagearbeitsplätze*") designs the manual assembly workplaces (see Figure 11, left). This tool enables to configure several alternative solutions of manual assembly workplaces and then evaluate them in terms of economic and ergonomic aspects. At the end of the planning chain activities is a 3D-presentation of the planning result with bills of materials. For this purpose AutoCAD program has been expanded to the application program CARLA (CAD-Workplace-Layout).

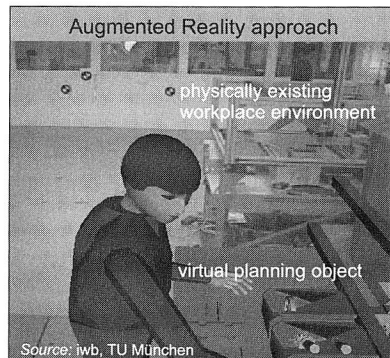
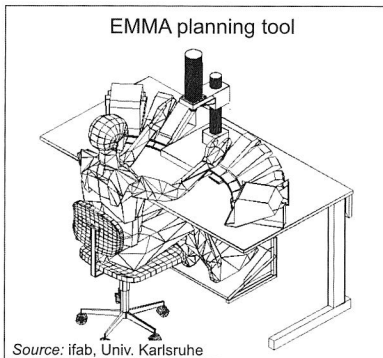


Figure 11: Approaches for designing manual assembly workplaces

2.5 Other Planning Approaches and Tools for Planning of Assembly Systems

Other planning approaches for planning of assembly systems include Virtual and Augmented Reality as well as participative and team-based approach. The planning tools

refer to these approaches including the Augmented Reality from iwB, Virtual Planner from IMS GmbH and Planning Table from Fraunhofer IPA.

2.5.1 IwB's Augmented Reality Approach

The Institute for Machine Tools and Industrial Management (iwB) at Technical University Munich has developed an Augmented Reality (AR) approach for designing manual assembly workplaces [132]. This technology is an enhancement of Virtual Reality. Augmented Reality also offers a new potential approach for industrial planning processes including layout design of manual workplaces. Using this technique, a physically existing workplace environment can be superimposed with virtual planning objects (see Figure 11, right).

2.5.2 Virtual Planner Software Solution

The Virtual Planner software solution can create both stereoscopic visualisations (in the narrow sense of Virtual Reality) and classical 3D visualisations (Figure 12, left). This solution uses all prevalent types of projection devices from the Head-Mounted-Display to the VR-cube for the purpose of visualisation. The implementation of the Virtual Planner as a Virtual Reality tool appears as a natural medium for three-dimensional computer supported collaborative work. It provides an interdisciplinary discussion platform and unites the different knowledge potentials of all participating persons in the project through comprehensible visualisations. Apart from the mere visualisation, Virtual Planner provides a VR-tool, which can be integrated into the planning process. By using the tool together with other planning tools, a holistic process chain is achieved which enables the user to save time and costs as well as to improve the quality of the planning and realisation stages.

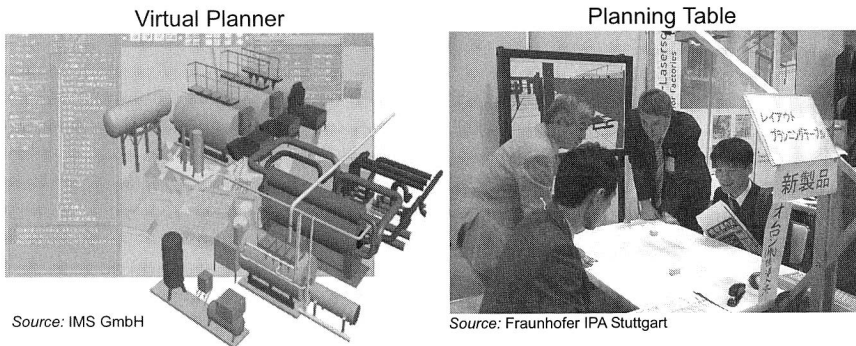


Figure 12: Computer tools for layout planning

2.5.3 Participative and Team-based Approach Using Planning Table

The Fraunhofer⁵ IPA (Institut für Produktionstechnik und Automatisierung) has developed a table, which enables participative and team-based planning (see Figure 12, right). This system called Planning Table also increases the planning quality and encourages communication. The system has the objective to place creativity in the forefront, while the computer slips into the background. Working with the Planning Table means that the planners don't see a computer. It is hidden underneath and there is no computer display. In order to enable the planners to envisage their facility in spatial terms, a three-dimensional picture is also projected onto the wall. This new platform concept is currently being developed on the basis of the software of the Planning Table system called i-plant [161].

2.6 Requirements Determination and Proposed Solution Approaches

This section begins with a summary of several issues, approaches and tools for the planning of assembly systems, which have been presented in the previous sections. The deficiencies in the planning of assembly systems will be identified according to today's technologies stands and certain solution approaches will be proposed in order to overcome the insufficient requirements.

One of the planning issues is increasing flexibility in the assembly systems due to today's changing market demands. The current literatures have revealed that modularisation of the assembly system facilities is considered to be a solution to the increasing flexibility. As a matter of fact, the availability of an efficient planning approach, which aids the planner to particularly design and simulate modular assembly systems by means of virtual models, is insufficient. In this context, a solution approach is proposed to develop an integrated approach for a 3D modelling of the system components as well as assembly lines with modular designs in a Virtual Manufacturing environment. Thus, a seamless integration between the digital models of assembly lines and the simulation concerning material flow and cost aspect can be performed. The main aspect of this solution approach is the development of several templates for modelling the modular components and systems (see Chapter 3). The ergonomic consideration in the manual assembly workplaces is a further issue. The requirement towards quantitative and qualitative ergonomic parameters is considered as important factors in improving these work systems. Therefore, a Virtual Manufacturing approach is proposed, which involves human simulation during performing the assembly tasks to obtain several ergonomic parameters. These parameters are considered to be important information for building alternative potential improvements of the manual assembly workplaces (see Chapter 4).

Researchers, institutions and commercial software companies have developed several methods and tools for the planning of assembly systems. Most of them develop their

⁵ Fraunhofer is a German research organisation named after the German physicist Joseph von Fraunhofer, with 58 institutes spread over Germany focussing on different fields of applied science.

planning methodology with a procedure model, which is structured in terms of planning contents and level of detail. The planning contents can include several tasks such as process planning, line balancing, system planning or workplace design. On the other hand, the procedure model can be stepped into a rough and detailed planning. Most of the planning methods are an iterative process, which aims at finding a better solution. Computer integrated approaches for planning assembly systems are also considered to be an advanced method, which help to achieve a simultaneous product engineering and production planning in the earliest stage. This approach will accelerate planning processes and ensure the planning results before going to the implementation stage. The core of this system is a data model, which manages the information required for the production planning. Several tools, which are based on Virtual and Augmented Reality approach, are other systems for planning and design purposes. The advantage of these systems is the spatial impression and enabling collaborative planning for the users. In a similar case, a participative and team-based planning approach like Planning Table tool has been delivered on the market to increase planning quality and to encourage communication between parties. Both approaches support a collaborative work between several planning members, but transmission of information occurs only at the same time and in the same location.

In the face of current competitive situation and increasing of global cooperation among geographically distributed teams, an important issue in the present planning process is collaboration between planners in different locations [54], [95], [137]. According to the review of current computer tools, which have been explored previously, there are insufficient planning tools with supporting collaborative work. On the other hand, several collaborative support technologies offer a time/place communication framework (see Figure 13). In connection with these technologies, a Web-based system enables any-time/anyplace collaboration over the Internet. This capability will be utilised to propose an alternative solution approach for virtual and collaborative planning of assembly systems over the Internet.

	Same Time (Synchron)	Different Time (Asynchron)
Same Place	<ul style="list-style-type: none"> - Meeting room - Web-based system ✓ - Multimedia Presentation - Whiteboard - Document sharing 	<ul style="list-style-type: none"> - Web-based system ✓ - Workflow management syst. - Document sharing - Email - Computer conferencing with playback
Different Place	<ul style="list-style-type: none"> - Web-based system ✓ - Videoconferencing - Audioconferencing - Email - Document sharing 	<ul style="list-style-type: none"> - Web-based System ✓ - Email - Workflow Management sys. - Document sharing - Computer conferencing with playback

Figure 13: Time/place communication framework and several collaborative support technologies

The following aspects should be considered when developing a Web-based planning tool:

- structuring the planning processes in terms of contents and level of detail
- integration of the planning processes with 3D visualisations
- distributed collaborative virtual environments for multi-user interactions
- integration of the external resource data (e.g. from supplier) in the process
- anytime/anyplace collaborations
- industry-standard and a platform-independent based file format for the developed system.

3 An Approach for Planning of Modular Assembly Lines in a Virtual Manufacturing Environment

A review of the current literature has revealed a trend towards modularisation, which increases assembly flexibility [47], [60]. The reconfigurability of such modular systems facilitates the adjustment and expansion of the production volume as well as the layout structure. Therefore, this chapter focuses on the development of an engineering environment for planning of modular assembly systems in a Virtual Manufacturing environment. In this context, the term “Virtual Manufacturing” emphasises the use of computer generated three-dimensional models (also called digital models) that represent the physical and logical schema and behaviour of a real manufacturing system. It provides a modelling and simulation environment, so that the design and production of manufactured products, including the associated manufacturing processes and system design, can be performed on the computer [75], [94], [123].

In connection with the planning of modular assembly systems, this chapter presents an integrated approach for modelling of modular components as well as their configurations. This approach includes the deployment of new templates within existing software as reference patterns for generating various digital models of modular components. By means of these templates, the users are guided to set several parameter values and thus, an individual digital model is generated and associated information is created automatically. Also, using the same approach, modular components can be assigned to an assembly line in an interactive three-dimensional graphical environment. A knowledge-based system, which assists component selection, has been developed and incorporated into the system. In addition, a layout structure assigned to a modular assembly line can also be reconfigured.

The modelling approach should prepare a seamless integration of generated assembly line models into the simulation concerning the material flow. Furthermore, other generated data, e.g. prices of components, are incorporated into the planning software as basic data in order to perform assembly cost analyses. This approach enables planning and simulation of modular assembly lines in different scenarios. In addition, a virtual manufacturing environment with computer-generated 3D models can be associated with the visualisation of the planning results.

3.1 Modular Concept for Flexible Assembly Systems

Today's changing market demands such as shorter delivery times, higher variant spectrum together with decreasing lot size require high flexible assembly systems. Automated assemblies that have been originally designed and optimised for special purposes and high volumes, now require in many cases increased flexibility. This also includes the necessary time to bring a new product to market. The biggest profit margin and thus shortest pay back period can be achieved by introducing a new product into the market as early as possible. To support this goal, it has been proposed that assem-

bly line flexibility should be attained through a modular construction. Generally, flexibility requirements of an assembly system (see Figure 14) have been differentiated on the basis of product, variant and volume flexibility [46], [47].

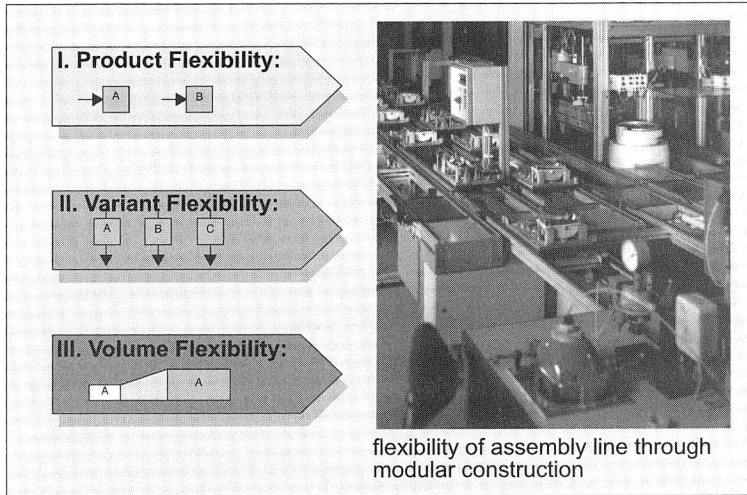


Figure 14: Flexibility requirements of the assembly systems [47].

An evaluation of 80 European manufacturers' product ranges of assembly systems has revealed a significant trend towards modular assembly systems [48]. The modular systems can be subdivided into modular construction-systems, module-systems and modular complete-systems (Figure 15).

Modular construction-systems have the highest number of individual components. On the one hand, the primary advantage of these systems is the almost unrestricted adaptability to the required assembly task. On the other hand, planning and realising such a system is expensive due to the complexity and programming effort involved. Module-systems consist of basic modules ready for immediate use. All function-determining system components (drives, conveyors, etc.) are already equipped with local controls and interfaces. Module-systems enable "plug and produce" operations, which lead to a considerable reduction in planning and realisation expenditure. Using this type of system could save additional expenditure and time. Modular complete-systems are assembly systems that are equipped with all components, including work drives that are necessary for conducting the assembly tasks. These systems are characterised by a high productivity and a very fast initiation. However, the systems normally carry out only certain functions to solve the required assembly task. Furthermore, the costs are higher and less flexible according to the modifications [8], [49], [150].

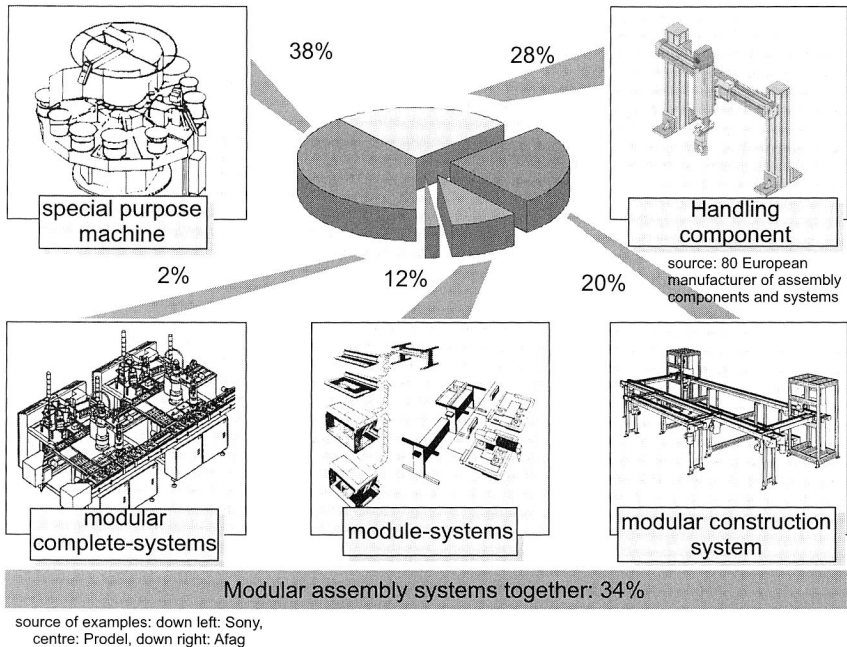


Figure 15: Market analysis of modular assembly systems [48].

Due to its modular design, these assembly systems are able to react to product variants and volume fluctuations, since this type of structure can be adapted to the production requirements. Capacity can be gradually increased by adding more workstations or modules for automated processes. Therefore, the investment is based on short-term future capacity requirements. Thus, with a modular system structure, it is possible to make changes several times a year. The modular components make it easier and more cost-effective for a company to make small production batches and protect their long-term investments in the flexible assembly system [60].

3.2 An Approach for Modelling Modular Assembly Lines

This section introduces a conceptual approach to three-dimensional modelling of modular assembly lines. The aim of the approach is to develop acceleration in the planning process, especially in generating 3D components (digital model) of modular assembly systems. Thus, by means of digital models a configurable assembly line structure can be carried out as well as an improved visualisation of the planning result. The modelling approach enables to parametrically generate the components with modular designs, then assign them corresponding pre-defined simulation types as well as price and weight information. Thus, a seamless integration of the 3D layout of an assembly line

and material flow simulation could be accomplished by using this approach. In addition, a digital model with price and weight information provides basic data to perform assembly cost analyses.

3.2.1 Three-Dimensional Geometric Modelling

The developing of a conceptual approach for systematic modelling of modular assembly lines requires a brief review of three-dimensional geometric modelling. There are three main types of three-dimensional geometric modelling used, namely line or wire frame modelling, surface modelling and solid modelling [63]. Each method has its own particular application in three-dimensional CAD systems. Solid modelling becomes more important and has been widely recognised, because there is no ambiguity in using a solid model to represent a real world 3D object. The designer takes this modelling into areas of greater realism. This modelling method is a rapidly growing area of research and development in a variety of applications. These are for example engineering, product design, computer-aided manufacturing, production layout and motion planning. All these applications require three-dimensional models to represent solid physical objects.

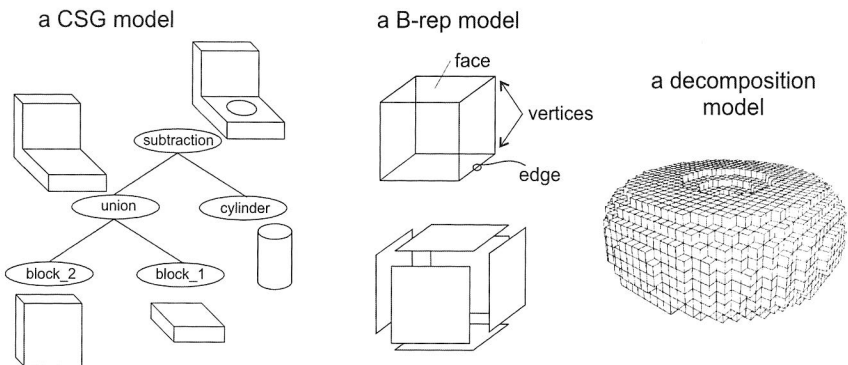


Figure 16: Types of solid modelling representation.

Two major representation schemes used in solid modelling are constructive solid geometry (abbreviated CSG) and boundary representations (abbreviated B-rep) [63]. In CSG, a three-dimensional model is represented as a set-theoretic Boolean expression of primitive solid objects. Those primitives are for example cubes, spheres, cones, cylinders and torus. In CSG, the surface and the interior of an object are defined implicitly. On the other hand, a B-rep describes only the surface of a solid as a data structure composed of vertices, edges and faces (Figure 16).

CSG and B-rep both have strengths and weaknesses. Therefore, the two representation schemes are usually combined in an effort to take advantage of the different strong points of both schemes. Apart from these two schemes, there is a number of solid rep-

representations based on spatial decomposition. One example is the well-known octree representation [89].

In this work, the representation scheme of the three-dimensional models focuses on boundary representation (B-rep). The definition of 3D bodies is based on the hierarchical structure shown in Figure 17. A 3D body can be defined either as a primitive or as an object. An object can be made up of primitives.

The boundary representation model (B-rep model) is used to model primitives e.g. squares, rectangles, cylinders, pyramids or sweep components. Primitives that are defined by a B-rep model consist of faces, edges, vertices, all of which enclosing its volume. In contrast to other solid models, such as the CSG model, the B-rep model has the advantage of being able to calculate collisions and movement quickly and easily [141]. Each 3D body that is placed in a 3D world is described by its geometry data, its position and orientation data and a number of attributes.

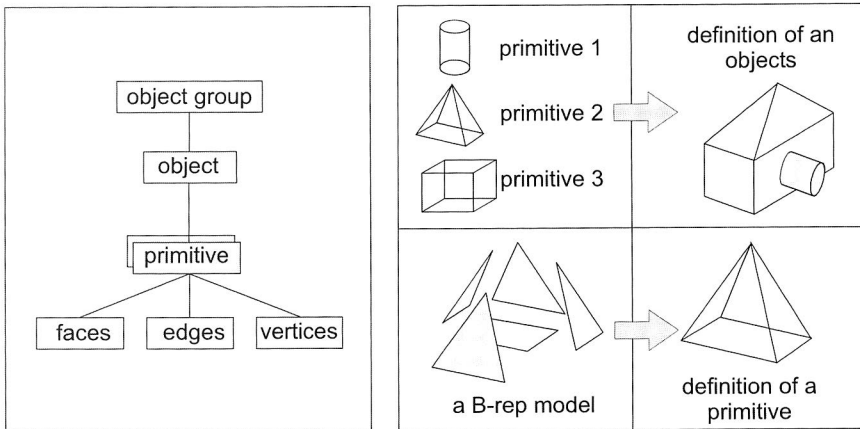


Figure 17: Definition of 3D bodies in a hierarchical structure

3.2.2 Primitive Instancing

This modelling scheme provides a set of all possible object shapes (primitive types), which are described by a set of parameters. Varying these parameters can create instances of any primitive type. Three-dimensional modelling that uses this method can construct more complex objects by transforming the instances of their primitive types. Cuboids, cylinders, spheres, L-profile and cones are some of the typical object shapes offered by these modelling schemes.

Figure 18 shows a simple primitive type that could be used for 3D model buildings. A parameter vector $P = (a, b, h, s_1, s_2)^T$ describes an object shape (L-profile). Individual instances of this primitive type generate different 3D bodies, which are according to

their parameter values. A set of the 3D bodies (instances of the primitive types) can also be transformed in a three-dimensional space by using translation vectors and rotation angles. Thus, it is possible to compose a 3D representation of assembly system components.

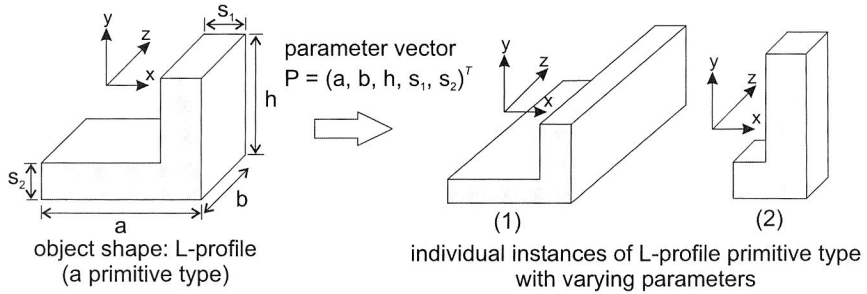


Figure 18: A parameterised primitive instancing technique.

Of course, by using this modelling technique, one is restricted by a library of primitive types. Only 3D bodies, which are corresponding to one of the pre-defined primitive types, can be used to construct 3D models. On the other hand, providing a large number of primitive types in a library results in an enormous programming effort, as a tailored code is required for each primitive type. However, for the primitive types contained in the library, modelling becomes very easy and efficient. This modelling scheme is still supported by many CAD and modelling systems as an auxiliary technique for the representation of often-needed system elements or components, even though the modelling system itself is based on other representations [85], [147].

3.2.3 Parameterisable Modelling of Components with Modular Designs

An assembly line with modular design consists of a large number of standardised modular components. A certain range of size and technical parameters specifies most of these components. In order to generate a particular modular component in digital forms, a set of corresponding parameters should be specified in the templates. These templates function as pre-designed masks for storing various parameter values. To accomplish these requirements, there has been used a parameterisable three-dimensional geometric modelling by using the technique of the primitive instancing along with boundary representation model. According to this technique, a component with modular design has been composed of various 3D bodies that consist of parametric instances of several primitive types like cuboid, cylinder, L-profile, etc.

This modelling technique allows the parameterisation of the various primitive types, which will compose 3D models of components with modular designs. Consequently, an individual model of modular component is generated according to the specified parameter values. In addition to the generation of digital models, other object information such

as component name, dimensions, price or weight, can be added to the 3D object (Figure 19). This technique offers advantages of an extremely reduction of required time for creating 3D models as well as an improved flexibility.

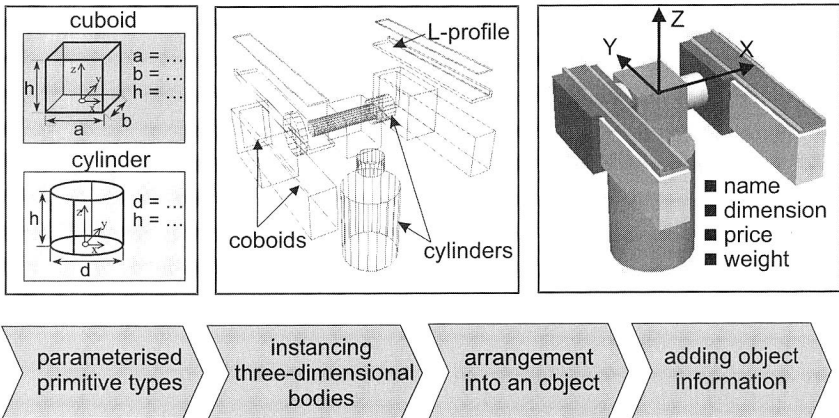


Figure 19: Parameterisable modelling for components with modular design

3.2.4 Integrated Modelling of Components with Modular Designs

The modular designs of assembly line elements, for instance belt sections, transverse conveyors, curve modules or workstations are objects or modules that represent material flow components inside the assembly area. To secure a planning result and to examine the dynamic performance of systems as well as their problems, the flow of material should be simulated in advance by means of simulation tools. In connection with three-dimensional modelling of modular design components, the integrated modelling approach incorporates the assignment of simulation types of component's material flow. The results of this modelling approach are pre-designed component types. They function as templates, which create modular component models. The digital models, which are generated by using this method, have particular simulation types concerning their material flow characteristics. Subsequently, the modular components can be composed in order to construct an assembly configuration, e.g. a transfer line with several stations. Thus, a seamless integration between the 3D assembly line model and material flow simulation process can be performed by means of this approach.

Moreover, the assignment of major information to the respective modular component such as price and weight is also integrated in the three-dimensional modelling procedures. Thus, this component information would be calculated according to the formulas, which refer to the component parameters such as length, width, thickness or number of motor. Altogether, the values specified to the component parameters will automatically generate a specific geometric model of modular component as well as certain simula-

tion type properties and component information. Changes made to the parameter values will affect the respective component properties.

The prices or weight information of components normally correspond to typical one on the market. Thus, the user is allowed to plan and to estimate without having to refer to specific suppliers or manufacturers. Furthermore, it enables the user to quickly add the new component models according to the indicated specification that are currently not available in the component database.

Figure 20 shows a digital model of a curve module generated by this modelling approach. Simulation type properties in macro for this curve module are also given in the right hand side of this figure. A curve module model is parameterised by track width and curve angle. Using this approach, this digital model will also integrate the assignment of its simulation type. The pre-defined simulation types of the curve module involved consist of 3 straight lines and 2 curves. Using programmable macro language ISEGRIM, the properties of each element can be set. The following ISEGRIM command for programming simulation properties in macros e.g. `sim_line(x1,y1,z1,x2,y2,z2,width)`, defines a simulation type "straight line", a starting point $P_1(x_1, y_1, z_1)$, an ending point $P_2(x_2, y_2, z_2)$ and "width" defines the width of the transformation path. The 3D models with pre-defined simulation types would be normally composed of a digital model of an assembly line and then could be generated into a simulation model. This model enables building up and initialising with a material flow simulation program, e.g. Dosimis or Simple++, and running in the simulator environment.

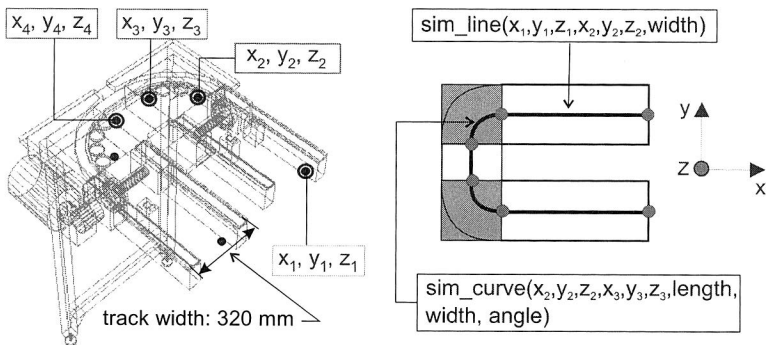


Figure 20: Three-dimensional parameterisable modelling including simulation types

The parameterisable modelling, including the formulas for prices as well as weight, is shown in Figure 21. The prices of a longitudinal conveyor have been calculated according to the specified parameter values, in this case width, length and number of motors. The same programmable graphics macro is used to write the formula. Once the parameter value of the conveyor module is defined, a digital model and the respective price as well as weight information will be generated. On the one hand, the digital com-

ponents with price and weight information provide the accelerating of 3D assembly line layout and on the other hand deliver the basic data to calculate and analyse the assembly costs.

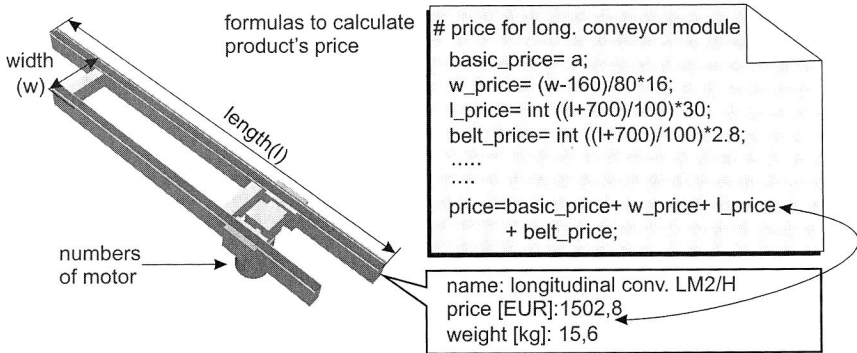


Figure 21: Parameterisable 3D modelling incorporating the formulas for the component's price and weight

3.3 Realisation of the Modelling Concept

The realisation of the modelling concept utilises a programmable macro language for 3D graphic objects called ISEGRIM (acronym for German name "Interpreter Language for Generating Graphic Interactive Macros"), which is an integrated part of the commercial software Ergoplan⁶ from Delmia. Using this macro, the approach to parametrically generate 3D objects that represent a component of a modular construction can be conducted. Moreover, the modelling process also incorporates simulation type properties as well as other major component information like price or weight. Using the same macro allows us to compose numerous digital models of components into an assembly line structure. In order for this concept to be realised, the reconfigurability of assembly line models must also be considered. .

3.3.1 Macro Programming of Three-Dimensional Graphics Object

Macro language is a simplified programming language, often incorporated into a sophisticated software application. There are several functionalities of a macro language. Most of them allow the user to automate certain tasks or to generate new applications as well as to expand features based on the standard systems.

The macro language ISEGRIM consists of two types of macros called "*graphic macros*" and "*bill of components macros*". The graphics macros are used to create 3D bodies, which are instanced from pre-defined primitive types of a system library. Subsequently,

⁶ The new released version of software Ergoplan is called Delmia Process Engineer

macros will transform them in order to construct a digital model, which represents an individual modular component. The next step of the macros programming consists in the assignment of simulation types and other information of the generated component mode. Another type of macros, called bill of component macros, organises the generated digital models, which have been produced by graphics macros. These macros compose them into a configuration according to the parameters, which have been defined previously. Thus, a modular assembly line can be digitally configured. This method also enables a current modular assembly line to be reconfigured into another assembly line.

Figure 18 shows a simple graphic macros program in order to illustrate an integrated modelling approach to generate a digital model of modular component. This macro programming language provides numerous operators, data types, functions, subprograms and procedures that enable the creation of number of macros as well as their processing and using for planning.

```
hauptprogramm (l,w): graphik
w= (160,240,320);
l.text="length:";
w.text="width:";
..
{
```

```
...
pr_1=einfuegen("quader", l, 45, 75);
pr_2=kopieren (pr_1);
pr_3=einfuegen("quader", 45, w-90, 65);
pr_4=einfuegen("zylinder", 25, w-90);
```

```
...
setze_position (pr_1, l/2, w/2-22.5, 0);
...
setze_drehung(pr_4, 90, 0, 0);
...
```

```
...
sim_line (0, 0, z1, l, 0, z1, w);
...
form_preis_1= .....;
form_preis_2= .....;
preis= form_preis_1+form_preis_2;
....}
```

instancing
parameterised
primitives

transformation
of objects

assignment of
simulation properties
& price information

a template dialog box

component designation	
length:	<input type="text"/>
width:	<input type="text" value="160"/> <input type="text" value="240"/> <input type="text" value="320"/>

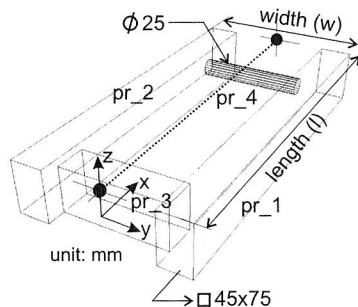


Figure 22: A simple graphic macro program and its result

3.3.2 Generating Three-Dimensional Components

Figure 23 shows an example application of the parameterised 3D modelling technique. The modular component, in this case a belt section, is specified by means of dialog templates, which will guide the user to store some parameters such as track width, track length, number of motors, band velocity and voltage/frequency of the drive motor. Assigning the parameter values to the reference templates generates a 3D model of the

module. The next step is the calculation of its information like price and weight as well as creating its simulation types. In this manner, modifying the component parameters can also be performed. For instance, the track length of the belt section has been modified into a new value. For this purpose, the “*Modify*” function of the software tool (Ergoplan) is applied. This action will appear the same templates once again and the users can re-enter the new parameter values in order to generate a corresponding 3D model. Thus, the updating of either component information or their corresponding simulation types follows this process.

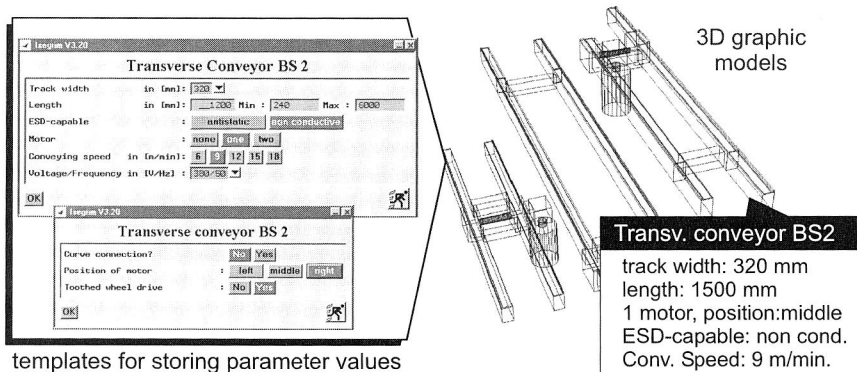


Figure 23: Automated generation of modular conveyor systems using templates

3.3.3 Configuration of Modular Assembly Line

The macro programming language can be used not only to automatically generate the digital models of components with modular design, but also to assign them to specified assembly line configurations. The “*bill of components macros*” is responsible for this task. In addition, algorithms, which assign and manipulate 3D objects, add rules or apply formulas, can also be written within the macros.

An example implementation for digital configuration of a modular transfer system from Bosch Rexroth (MTS-2) is shown in Figure 24. This figure shows a dialog template, which defines the layout configuration by several parameters. Parameters such as track width, table depth, number of stations, distance between two stations, and other technical information like electrostatic discharge protection and conveying speed can be stored by the user. The macros program will firstly specify the initial parameter values. Subsequently, sequences of other dialog templates will promptly appear. Using a sequence of these templates, the parameter values can be specified by the planner. This process is followed by the assignment of the specified digital components to an assembly line. As a result, a layout configuration (see Figure 20) consists of several modular components with price and weight information as well as defined simulation types.

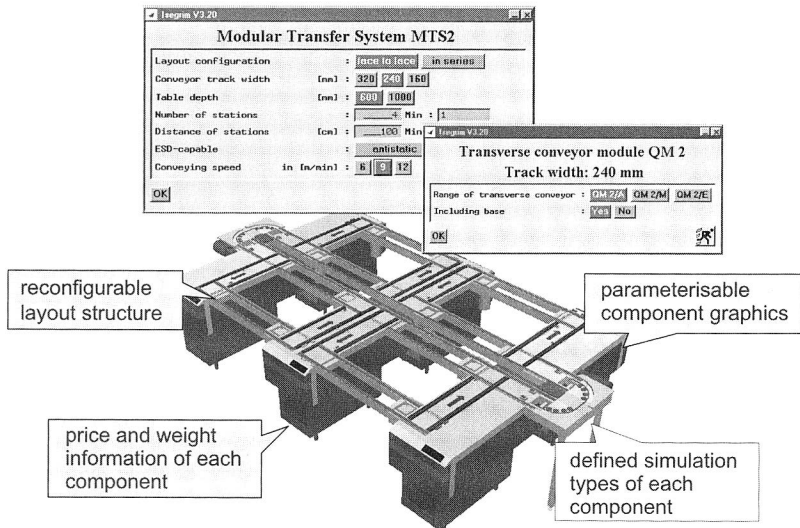


Figure 24: Configuration of digital models for a modular transfer line

Rules can be incorporated into the model to form the basis of a knowledge system. Figure 25 depicts an “if-then rule” by choosing an appropriate modular component. This algorithm, which has been pre-programmed, allows comparing the user-specified parameter values with pre-defined system values automatically. Consequently, the program will select a proper component and determine its dimensions, generate a 3D model as well as calculate the price and weight of the selected component.

A modular system structure can be reconfigured to adapt to changes in production volume or product variants. The addition of more parallel workstations or automated assembly process has been performed gradually to increase capacity. System configuration can be developed according to the product life cycle. For example, product volume and layout configuration changes can be accomplished in several stages [131]. These requirements must be fulfilled to enable the digital components of a given layout structure to be easily reconfigured into another structure. Otherwise, the effect of modifying the 3D model of a component will also update the other parameters, so that further analysis can easily be performed.

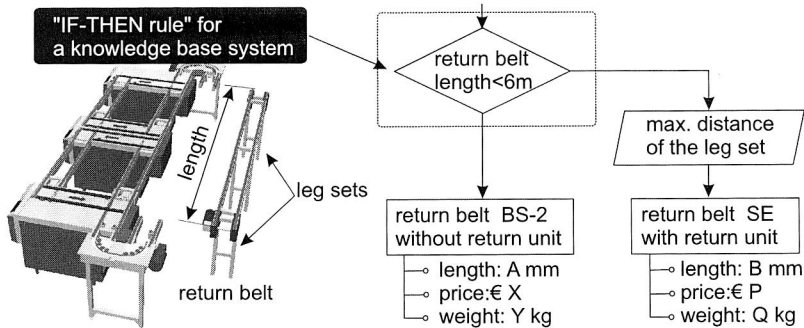


Figure 25: Rules incorporated in the model generation

Figure 26 shows two exemplary layout structures. The first layout consists of transfer system elements with an *"in series, face to face"* configuration for six workstations. This layout has been reconfigured digitally into a transfer system configuration with four workstations. The system has updated the configuration information to reflect the new layout structure. This includes the list of components (component description, order number etc.), the total price and weight (summation from each individual component's price and weight data) and the model for material flow simulation.

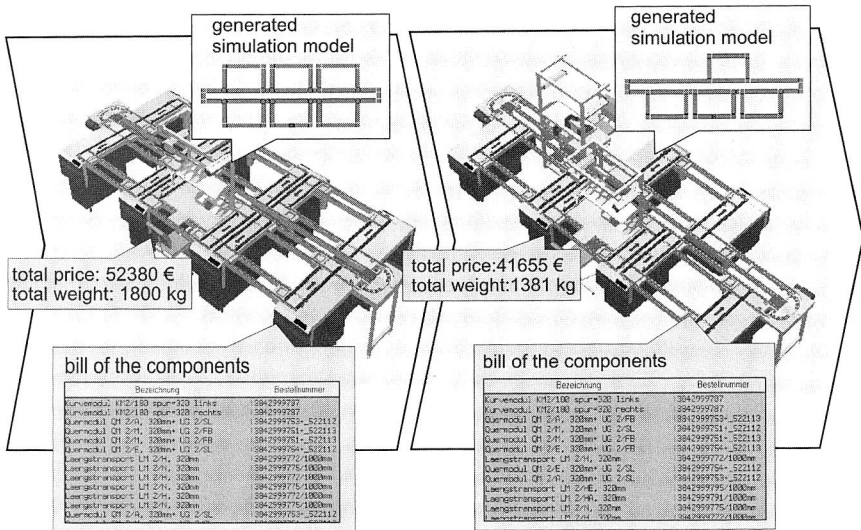


Figure 26: Reconfiguration ability of digital models of modular transfer systems

3.4 Seamless Integration between Three-Dimensional Assembly Line Model and Material Flow Simulation

After the modular components e.g. transfer system elements, workstations and other individual components have been assigned to a specific assembly line configuration; the next issue to be addressed is the logistics within the assembly area. Material flow simulation can be performed to meet this requirement. For this purpose, several simulation data are required to achieve the expected result. One data type is the time required to complete the sequence of operations in each workstation. If there is no data available, the time for the manual operations is predicted by a predetermined time system based on internationally established methods such as MTM⁷. It is suggested that assembly operation sequences should be defined by using time macros (library elements) based on MTM. A time macro is considered to be a defined operation sequence with description, operation method and code as well as analysis time. It functions as a highly compressed analysis module of MTM analysis from standard and repetitive activities. For instance, an assembly operation such as the manual mounting of electronic components with both hands should first be analysed with an MTM-basic motions method (very precise).

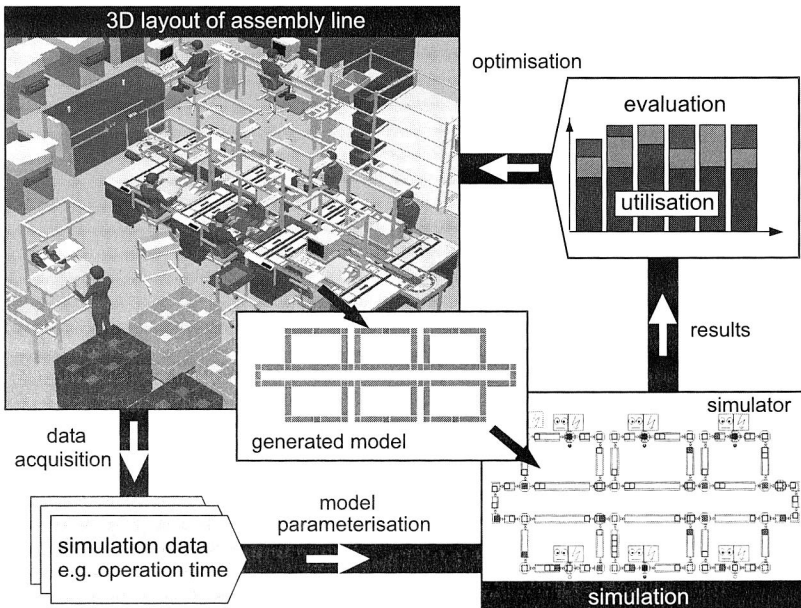


Figure 27: Seamless integration between 3D assembly line model and material flow simulation [111]

⁷ MTM stands for Method Time Measurement

Afterward, the result has to be saved as a library element for a repetitive operation (time macros). Consequently, the prediction of assembly operations will reuse the library elements. This is an efficient methodology to determine the time required to perform job sequences.

The configuration of the digital components in an assembly line and their simulation types are used to generate a model, which can be run afterwards by a material flow simulator (Figure 27). The simulator uses this model together with other simulation data e.g. product variants, lot size, assembly sequences, simulation-relevant data to the workstations or shift work data. The seamless integration between 3D assembly facilities layout planning and material flow simulation enables a number of factors e.g. lead time, production output, workstations utilisation or the optimal number of workpiece pallets, to be quickly calculated. This in turn allows the execution of simulations of modular assembly lines in different scenarios and the determination of best solution. Analyses can be made not only from a logistical point of view but also from the point of view of assembly cost for different line configurations.

3.4.1 Simulation Model for an Assembly Line

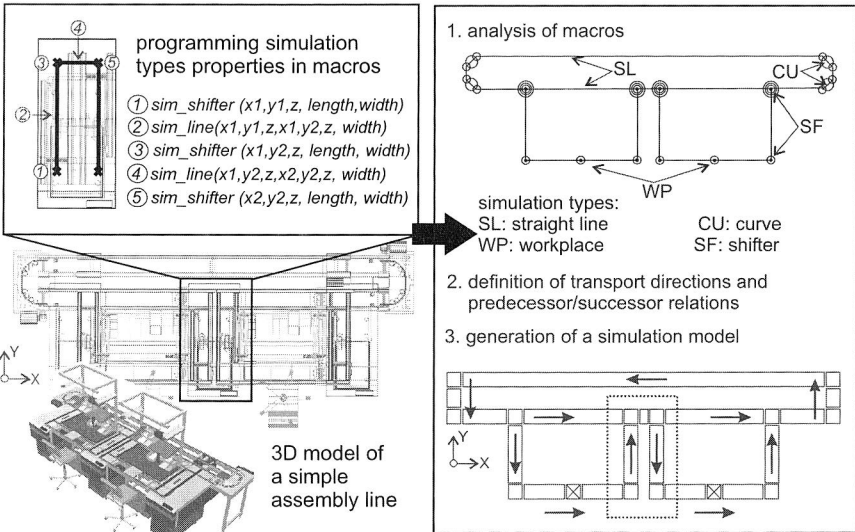


Figure 28: Model builder for simulation

In this section, the discussion focuses on the building of a simulation model from a 3D model of an assembly line. The procedure begins with a modelling concept, which has been implemented here (see section 3.2.4). Subsequently, a part of the software Ergoplan, called Ergosim, will analyse each digital model of an assembly line, particu-

larly the pre-programmed simulation types properties, written in macro language. The software will identify the simulation types of the 3D object such as straight lines, curves, workplaces or shifters together with their dimension properties. The next step is to define the transport directions and the predecessor/successor relationship among the simulation types. In the end, a simulation model will be generated, which is based on simulation types data sets obtained from 3D models (Figure 28).

Once the simulation model has been generated, simulation-relevant data of workstations and transfer systems should be stored. The data are useful to perform a material flow simulation within the assembly line layout that is created by using this method. They include processing times and the down behaviour of stations, buffers and transport speed of the transfer systems. In addition to these data, the system also provides dialog boxes, which store other simulation-relevant data such as work piece carriers, production plans, work plans and the worker-pool. The worker pool data particularly consist of employees, qualification, employment, path-time, break plan and shift model data.

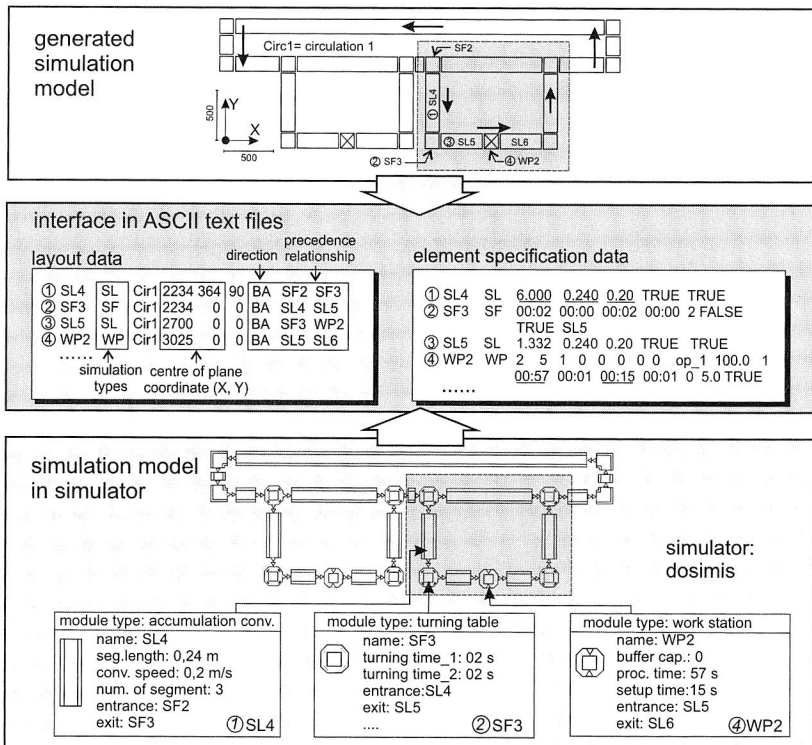


Figure 29: An interface between simulation model and simulator

Using the generated simulation model and simulation-relevant data, the system will create text files stored in ASCII format for interfacing purposes. A layout and an element specification data are parts of those text files. The layout data contains information about the designation, the simulation types, the centre of plane coordinate, the direction and the precedence relationship of each modular component, which result from macro analysis. The element specification data describes the components designation including their simulation types, the basic dimension (length, width), velocity of transfer component or processing time of stations, etc. The material flow simulator will subsequently read both text files and accordingly creates corresponding module types, e.g. workstations, accumulation conveyors. Thus, the simulator will automatically arrange these module types into a certain layout (Figure 29).

Additionally, a procedure will also generate other simulation-relevant data such as workpiece carrier, circulation, production plan, availability or shift data. As a result, more text files for interfacing processes have been created. The simulator will convert all ASCII text files into its format and certain procedure in the simulator will transform those formatted forms into a layout model. Subsequently, several module types in the simulator, e.g. accumulative conveyors, turning tables, source, sink, workstations, monitor or work-pools module types build this model (see Figure 30). In this stage, the layout model is ready to be simulated.

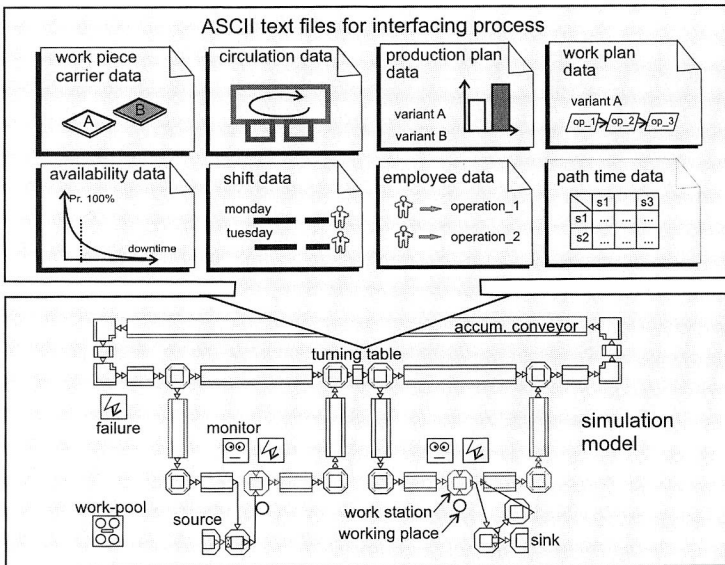


Figure 30: Building several module types in the material flow simulator

3.4.2 Simulation Results

Typical simulation results obtained for selected layout configurations for product variant assembly using the proposed modelling technique are shown in Figure 31. An assembly line with “in series, face to face” modular structures configuration composed of 10 stations has been generated by using the modelling technique described previously. Two product variants with their assembly operations are manually or partially automated assembled. The products are individually transported through the system by workpiece carriers, which flow with a conveyor system using track width 240 mm and speed 12 m/min. The simulation task is to determine a number of workpiece carrier, which results in the highest production output.

Figure 31 depicts the simulation result of a certain layout configuration generated by this approach. The diagram illustrates the application of the simulation technique by which the optimal number of workpiece carrier is determined. It can be seen that production output increases significantly in the case of workpiece carriers with 40 pieces (see Figure 31, left hand side). If the carrier contains more than 40 pieces, the fraction of blocked time of the 2 stations is increased (see Figure 31, right hand side). As a result, a decreasing production output is produced.

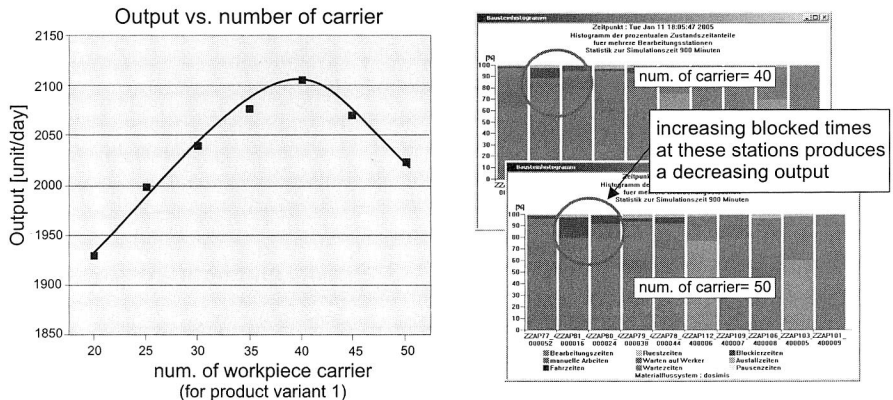


Figure 31: Simulation results of certain layout configuration

In addition to the supplementation of planning activities with a material flow simulation, the planning software, which performs an assembly cost calculation, can use data of component prices. This enables the conduction of the planning and simulations of modular assembly lines in different scenarios so that the optimal result is obtained. Concurrently, the correlation between the fixed cost determined by the bill of components system given by the assembly line configurations and the degree of utilisation indicated by the simulation results can be evaluated.

3.5 Visualisation of the Planning Result

The presentation of the planning data in an immersive virtual environment as a modern virtual development environment and a communication platform becomes increasingly important. The virtual reality system facilitates the development of the assembly line as well as the manual workstation. With both immersive presentation and interaction possibilities, planners and other interested parties can discuss the results of the digital models and exchange information.

In the context of visualisation in a virtual reality environment, digital models of workstations and assembly lines produced using a software tool have been converted into Virtual Reality Modelling Language (VRML) format. A visualisation screen, also known as a Powerwall, has been used to display a three-dimensional model of the workstation or line configuration in detail or in actual size. This virtual facility will primarily be used for small group discussions. Two projectors cast images of the generated model in stereo onto the semi-transparent screen, driven by a computer. The immersed person is able to navigate and interact with the virtual environment and perform tasks such as the arrangement of assembly workstations and layout of the assembly lines.

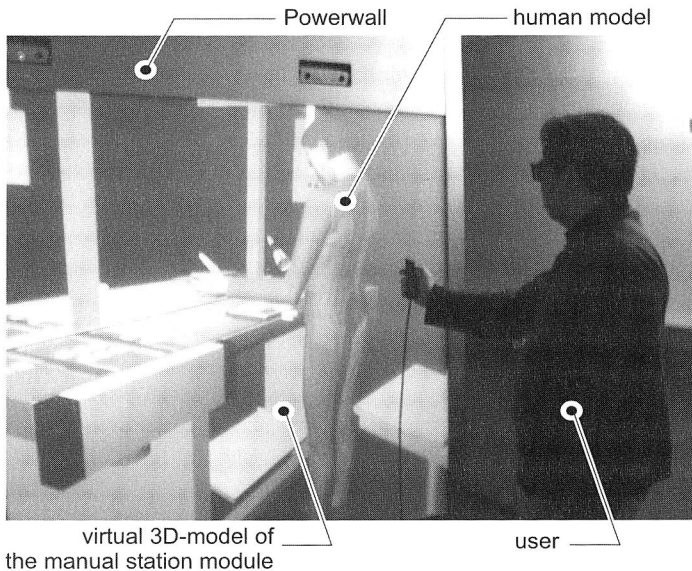


Figure 32: Visualisation of the planning result in the Powerwall

Figure 32 shows the presentation of a designed manual workstation including a human model in the virtual reality environment using a Powerwall⁸. In addition to this kind of presentation, another possibility to visualise 3D models is using the VRML format in a Web-based interactive collaborative environment. This visualisation method will be explained in detail in Chapter 7.

⁸ The Powerwall belong the *Lehrstuhl für Konstruktionstechnik*, Univ. Erlangen-Nuremberg.

4 Design of Manual Workplaces Using a Virtual Manufacturing Approach

The increasing demands for shorter delivery times, higher product variety, quality and decreasing manufacturing costs have forced manufacturers of complex products to improve the flow of assembly orders and the employment. There is an increasing awareness of motivated human resources for the success of companies. Therefore, most attention should be paid in this area particularly to the assembly processes, where the products get their final form. The improvement of assembly layouts and workplace designs should focus on both time reduction and increasing of the performance of the assembly task from an ergonomic point of view. In order to meet these demands, an integrated and computer-based method that improves manual assembly processes along with their assembly layouts and workplaces is needed.

Incorporating good ergonomic principles during the design stage of the manufacturing and assembly facilities, especially in the manual workplaces, has become increasingly important. This activity can result in many benefits, including reductions in development costs, increased process efficiency as well as improved worker safety and motivation. Planner and engineer are becoming more and more reliant upon ergonomic simulation tools to address these design issues. These simulation tools allow the designer to incorporate numerous workplace design aspects such as working postures, reach and visibility, enabling optimal ergonomic design on the performed tasks and the identification of the potential health risks.

Traditional workplace design and redesign, based on the results of ergonomics evaluations, are time consuming and often unfeasible in the industry. Therefore, modern design methods with application of computer-based tools are a promising solution. The Virtual Manufacturing approach using computer-generated three-dimensional human models on CAD software system enables manual workplaces to be designed and simulated virtually according to the anthropometric rules in order to get more comfortable postures and prevent human injuries. This kind of computer aided tool for workplace design simplifies the analysis of the human factors in working systems and allows a greater level of detail incorporated with a number of analyses.

4.1 Manual Workplace in the Assembly Systems

In spite of the increased automation efforts in the assembly systems in many companies, workers still perform most assembly operations. Manual assembly dominates the production of low-volume or mixed-technology products, where the assembly processes are highly variable or not consistently predictable or controllable or where proper assembly relies on individual experiences and proficiency. In addition, manual workplaces tend to involve bulk or limp materials and often-unstructured requirements. Therefore, manual assembly systems will still maintain their position in the future, and with increasing competition, the attention to the efficiency of manual work will continue to grow [25].

Due to related labour cost, optimising manual operations as well as workplaces in assembly systems is a very important aspect. The measures focus on lead-time reduction and increase of the performance of the assembly task from an ergonomic point of view.

Incorporating good ergonomic principles in the design of work systems has become increasingly important for the reduction of work-related injuries. A review of an European survey has revealed, that millions of European workers are affected by musculoskeletal disorders. Particularly in Germany, about 37% of all workers are affected by this injury [108]. This musculoskeletal disorder brings indirect costs (loss of productivity years by sick leave) and costs for disease treatment. Studies have found out that the task characteristics causing the musculoskeletal disorders are heavy works and works with repeated bending, twisting or increased reaching [22]. Besides work-related injuries, there are some types of situations like too low working surface, parts slightly out of reach, lighting not quite bright enough. Even if they seem insignificant, these factors can have a negative influence on the workers' efficiency, safety and motivation. In fact, many experts believe that more productivity is lost due to these types of situations than to actual physical illnesses. The rules of ergonomics can also help to design workplaces that are right for each worker and suitable for each task. As a result, maximum worker efficiency, safety and productivity should be achieved.

Manufacturers are more and more forced to improve the flow of assembly orders and their employment. The human factor for a well-motivated worker is also increasingly important and is needed more than ever. Therefore, a properly designed workplace can increase efficiency and workers' comfort. Virtual Manufacturing approaches that utilise digital models for planning and design of the manufacturing systems particularly manual assembly workplace can be applied for these purposes. The next sections discuss the effect of using this approach for manual workplaces in order to obtain an improvement in ergonomic as well as economic results.

4.1.1 Role of Worker in the Assembly Systems

The role of the worker in the assembly systems is crucial because today's companies are facing increasingly dynamic requirements. Examples include fluctuating quantity demands, increasing variety and rigorous delivery performance. A wide variety of products have to be delivered in varying amounts as fast as possible. Since lifespan of products are decreasing, the conditions are getting tougher. In order to keep up with the market's changing requirements, flexibility in production and assembly is mandatory. On the other hand, most of the rationalisation strategies are based on an increased automation, due to high personnel costs. However, a high level of automation and increasing interlinkage make production inflexible in respect of variety and fluctuation in quantity. Adaptations to changes cause also high costs. In view of this situation, production structures with a large proportion of manual activities offer a promising solution.

The influences described previously require a production and an assembly concept, which need to be strongly centred on the worker. The classical paradigm of rationalisa-

tion can be shifted to a human-oriented production concept. Paying attention to the role of the worker in production and assembly raises some important issues such as intelligent technologies for material handling and flow control, layout structure and organisation, hybrid and modular assembly systems as well as human information system and human factors (ergonomics features) in the workplace [60], [142].

The production concept, which pays attention to the role of the workers in the assembly places, also shows the actual economic advantage of the system in some degrees over the automation solution. According to an analysis made by IFA (*Institut für Fabrikanlage und Logistik*, Hannover) within the automobile industry, classical economics calculations for production systems consider only personnel and amortisation costs. That is why the automated systems often appear to be cheaper solutions than the manual systems. However, if operational costs such as interlinkage, reworking and maintenance are taken into account, it immediately becomes clear that the manual system has a cost advantage over the automated one (Figure 33) [164].

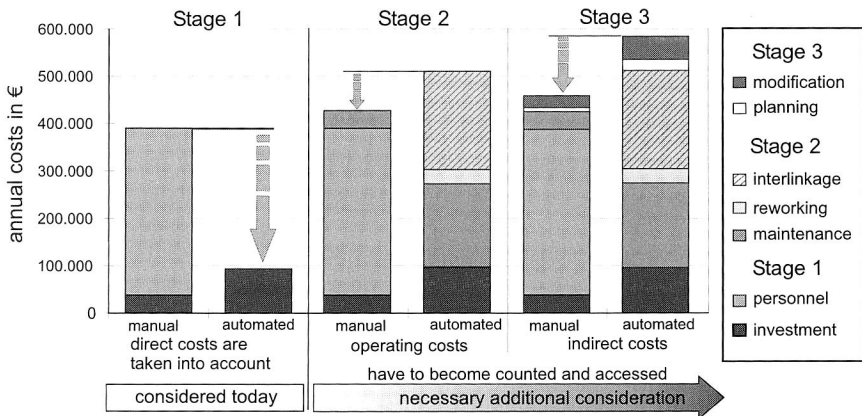


Figure 33: Comparing the manual and automatic assembly systems through an extensive cost consideration [164]

The analysis above also investigates the interlinkage of automation systems. This interlinkage causes massive cost. These losses are generally accepted during the planning of the production plant. However, in practice, they prove to be unacceptable. If, for example, the assembly is performed manually, the losses of interlinkage and reworking are minimised. Problems caused by technical aids, such as highly automated material transport systems, do not appear at all. Therefore, the application of manual production offers an interesting economic alternative, especially if a lot of flexibility is needed.

4.1.2 Ergonomics Issues

Ergonomics is an applied science of fitting workplace conditions and job demands to the capabilities of the working population. It aims to promote health and productivity in the workplace [62]. Effective and successful "*fits*" assure high productivity and efficiency, avoidance of illness and injury risks and increased comfort and job satisfaction among workers as well as their greater acceptance. Although the scope of ergonomics is much broader, the term for the design of manual workplace refers to the achievement of maximum worker efficiency and the assessment of work-related factors that may pose a risk of musculoskeletal disorders and recommendations to alleviate them.

An example of the ergonomic intervention in the workplace, which improves health and productivity, is given by a study of the Institute for Work and Health in Toronto [5]. This study examines the link between individual health and economic outcomes. It was found out that after receiving an adjustable chair and ergonomic training, workers reported less soft-tissue injury and pain and at the same time their productivity increased nearly 18 percent over the year.

Anthropometric Design

To achieve maximum worker efficiency, all elements of a work system should be optimally fitted to the demands of the human body. The human anthropometry, which is that part of ergonomics that deals with the dimensions of the human body, serves in this context as important data for the design of manual workplace in the assembly systems. The anthropometry data are distributed among the relevant population characteristic. Besides the human body dimensions factor, the determination of the workplace dimensions according to an anthropometric point of view is also affected by the work requirements (e.g. the task predominantly needs coordination of fine motor activity and visual controls) and the type and size of the work objects.

Anthropometric design rules also have to be considered for the design of grab areas. Placing items within easy reach helps to avoid body and arm twists and continuous wrist flexing when reaching for the parts. Furthermore, consideration of the field of vision should be considered in order to minimise eye movements and head turning during assembly operations.

Working Posture

The term "posture" describes the way in which one "holds" him and refers to the relationship between body parts. Posture is normally described in relation to "normal" posture, the position of minimal stress for muscles and joints. Poor posture and associated problems are common, because most of the daily activities are performed in front of the body so that it tends to slouch in this direction. Many musculoskeletal and joint problems result from poor posture and faulty body mechanics. These problems are also ergonomic issues in the design of manual workplace, particularly for design of manual lifting tasks.

According to Hall [59], the most of work-related injuries in the workplace are back injuries. Most of the back problems are low back injuries (70%). The low back is the lowest part of the spine, called the lumbar spine. This area usually has five vertebrae and this is where most of the weight bearing and body movement takes place. Typically, this is where workers tend to place too much pressure strains from lifting or lowering tasks. As shown in Figure 34, the body posture assumed in the manual lifting tasks like lateral bending will create compressive stresses on one side of the disc and tensile on the other. On the other hand, twisting produces shear stresses around the disc with its maximum on the outside. Both of the postures are poor postures and should be anticipated when designing the manual tasks in the workplace.

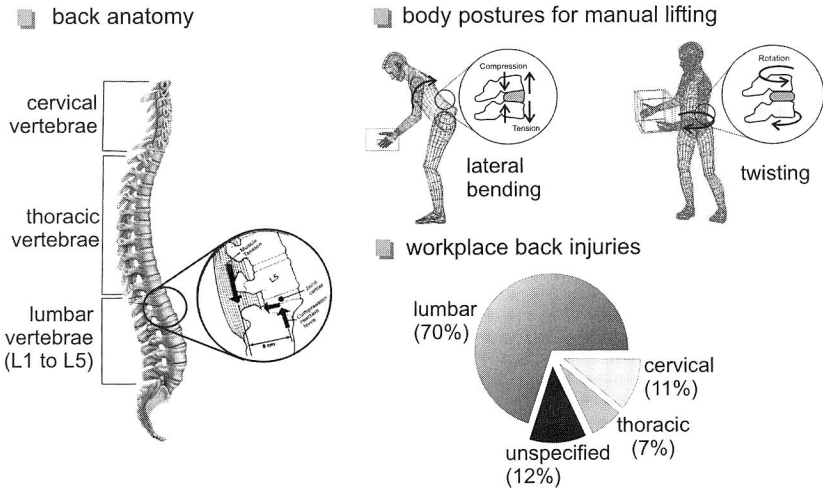


Figure 34: Relation between body posture and workplace injuries [59]

Work environments

Working environments such as lighting, climate, ventilation and noise are some factors that have to be considered in the designing of the workplace. For instance, correct lighting for a task will reduce errors and increase the worker's performance.

4.2 Virtual Manufacturing Approach for Improvement of Manual Workplaces

This section discusses the benefits of the Virtual Manufacturing approach to improve manual workplaces, particularly from the ergonomic point of view. A Virtual Manufacturing approach is presented as a computer-based simulated manufacturing development environment that enables the planners to "make it virtually" before "make it for real". It allows a manual workplace to be virtually designed and built with full simulation and

visualisation. This approach utilises computer generated three-dimensional models (also called *digital models*) to represent the physical and logical schema of real assembly systems, including human body models and other facilities of the manual workplaces.

4.2.1 Computer-generated Three-Dimensional Human Body Model

The computer-generated three-dimensional human body model (also called a computer manikin or digital human model) with simulation capabilities plays an important role in the Virtual Manufacturing approach. It helps to improve manual workplaces. Principally, this model is needed to design workplaces, to simulate the human tasks and to carry out ergonomics analysis in the virtual environments. Computer manikins can perform anthropometric geometrical aspects analysis in a workplace such as reach, vision and space. Various biomechanical analyses of the human body i.e. postural or manual lifting during work are integrated into the digital human model in order to evaluate the stress on the human bodies from an ergonomic point of view.

The structure of the virtual human is modelled as a series of rigid segments linked by hinge joints. The same model can be differently represented as a skeleton model, a wire frame or a solid model. The selected display of the virtual human model usually refers to the requirement for a computation speed of the virtual human motions or a real display of the human figure. One main difference between the different virtual human models is the number of segments and joints. A human model, called Anthropos [31], is one of the advanced virtual human models. It has the number of joints and the same properties as its real counterpart. Simple joints that contain several degrees of freedom can approach modelling the human joints. For instance, an elbow joint has only one degree of freedom. Other joints are more complicated and need to be made of multiple segments and joints that are coupled together, e.g. as in the shoulder joints.

The creation of three-dimensional human models is based on body dimension measurements taken from an anthropometric survey. Figure 35 depicts the human body dimensions in standing position according to the German standard (DIN 33402 part 2) [102]. The anthropometric data that accommodates most of the population have been used to develop the anthropometrical human models, e.g. the Anthropos model with 5th, 50th, and 95th percentile of both, male and female. The Anthropos models are used as three-dimensional graphical aids to design and optimise the manual tasks in the workplaces. More advanced human models are able to manipulate the body using so called inverse kinematics and pre-recorded postures. The use of this technique allows the user to move e.g. the hand of the virtual model, while the inverse kinematics algorithm calculates the according movements of the arm and the upper body as a chain of links that follows the movement of the hand. This technique makes it possible to easily simulate the human movements with reasonably good accuracy.

human body dimensions in [mm]						
standing position:	male 5%	male 50%	male 95%	female 5%	female 50%	female 95%
functional forward reach	668	723	791	615	693	772
body depth, standing	243	275	303	232	280	360
reach range to the top	1923	2061	2226	1755	1869	1992
body height	1645	1745	1852	1522	1629	1737
eye height	1511	1614	1720	1399	1500	1590
shoulder height	1373	1463	1562	1238	1348	1444
elbow height	1026	1099	1180	955	1031	1098
functional downward reach	732	774	832	660	740	811
shoulders breadth	370	400	429	326	359	407

(age-class: 26 to 40 years - according to DIN 33402, part 2)

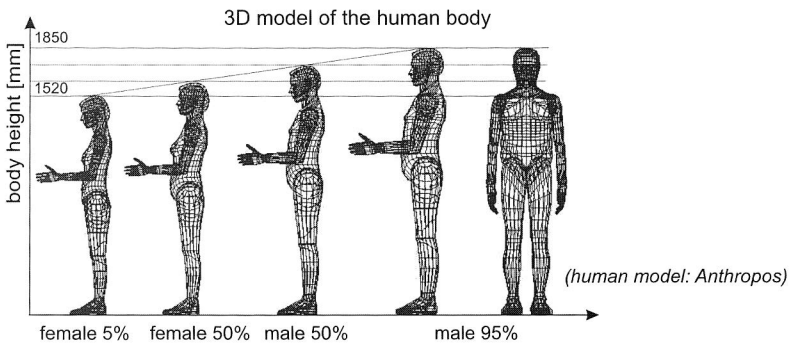


Figure 35: Dimensions and 3D models of human body

On the market, there are several different digital human model programs. Most of them have been developed using three-dimensional CAD programs with built-in ergonomics assessment capabilities. They include the Jack model from EDS-PLM [10], RAMSIS from Techmath [139] and SAMMIE [126]. Moreover, Delmia, one of the world's leader in the provision of digital manufacturing solutions, utilises several different virtual human model programs such as SAFEWORK, ANTHROPOS and RAMSIS integrated with its solutions like Envision/Ergo, Human Builder and Layout Planner (former Ergomas) [100], [122]. Many CAD, visualisation and simulation programs, e.g. Catia, 3D-Studio Max and others, are simply built in a virtual human model.

4.2.2 Three-Dimensional Workplace Layout Design

The workplace layout design incorporates ergonomic principles in order to fit the human doing the tasks with several elements of work systems. This actually means that the dimensioning of workplaces along with the selection and the arrangement of the workplace components, tools and parts is based on an anthropometric point of view. Certain factors like the human body dimensions, the work requirements and the work objects need to be taken into account (see Figure 36). For instance, a job predominantly needs coordination of fine motor activity and visual controls (e.g. the assembly of smallest

parts/precision work) require a higher work height. Conversely, a job's requirement for predominant freedom of hand movements needs a lower work height. Normally, it requires a work height about 50-100 mm above the elbow height. In addition, the work level for heavy work should be below elbow and depend on the size of the work object.

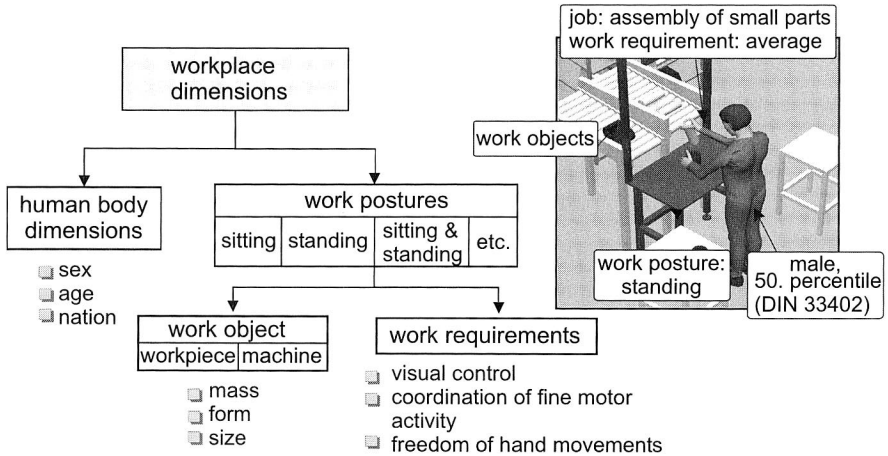


Figure 36: Factors taken into account for dimensioning manual workplaces [30]

Three-dimensional models of workplace facilities, work objects and the ambitious virtual human model allow a very realistic and graphical representation of the workplace layout design. The human model works with the standard percentiles 5th, 50th and 95th for men and women respectively, and can be assigned directly to the virtual designed workplace.

Operations or processes that involve human interaction undergo a basic ergonomic evaluation. A 5th percentile female is used to verify reach concerns and a 95th percentile male is used to assess hand clearances. For example, if the worker is required to install the centre console, a 5th percentile female would be simulated in order to capture potential horizontal reach concerns.

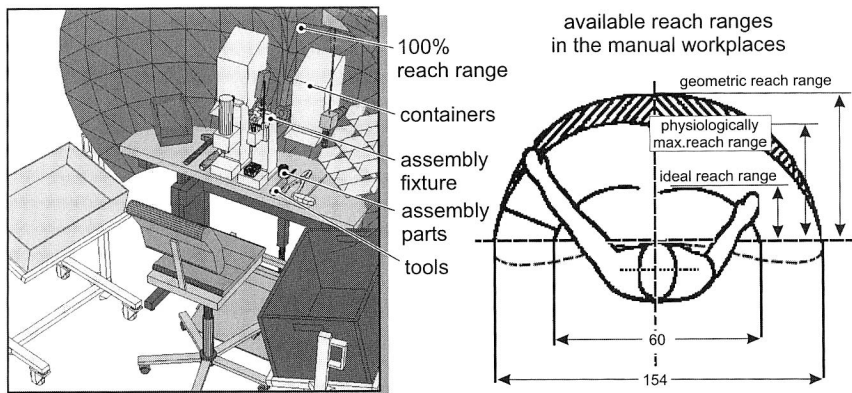


Figure 37: Assigning assembly resources within the reach area of the hands

Besides the virtual human model, the Virtual Manufacturing approach for designing the manual workplace is prepared with the several workspaces envelopes according to the defined reach range (Figure 37). The workspaces enveloped are defined as the 3D space around an individual in which it is reasonably optimal for persons to perform specific types of manual activity. Placing items within easy reach helps avoid body and arm twists and continuous wrist flexing when reaching for parts, and reduces repetitive motion injuries. For instance, all parts, tools, and fixture assembly should be placed within easy reach of the worker. All containers should be positioned in the physiologically maximum reach range. Containers mounted on adjustable, articulating arms follow easier the sweep of the work place envelope for the physiologically maximum reach range than containers mounted flat in the back of the workstation.

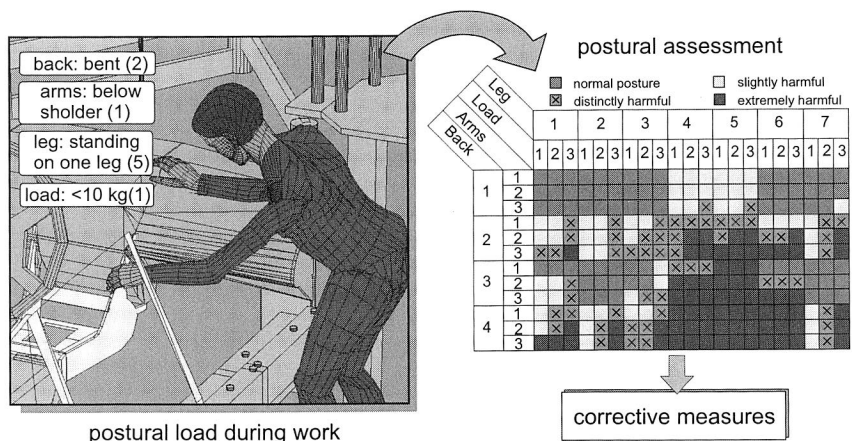


Figure 38: Posture analysis according to OWAS method

Another important aspect in designing and improving manual workplaces is the working posture during assembly tasks. Poor working postures have been identified as a cause of musculoskeletal disorders. Disorders of this type produce a high number of worker's compensation claims. Poor postures can be identified and improvements evaluated by analysing working postures. Thus, analysis should allow the number and severity of these disorders to be reduced.

Several systems for analysis of posture have been developed, most of them commercial software, which utilise a Virtual Manufacturing approach. They use the human posture analysis system, called OWAS (Ovako Working Posture Analysing System) [146]. It was developed in the Finnish steel industry between 1974-78 and later enhanced by the Finnish Centre for Occupational Safety. It defines postures according to the position of various body parts: back, arms, legs, and the effort being exerted. The software for ergonomically designing the workplace can perform motions simulation during assembly task. The postures information is sampled over a representative period for the work of interest. The data can be analysed by using a postural assessment system which grades the effect on the musculoskeletal system on a four point "action category" scale. Normally, this scale, which represents corrective measures, is also highlighted in a signal colour (green, yellow, orange, and red). Figure 38 illustrates the posture analysis during work as well as its postural assessment.

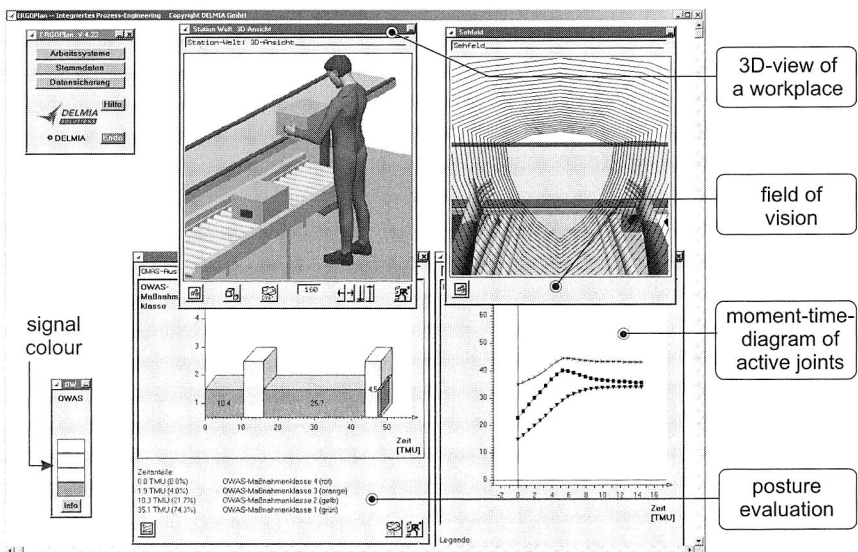


Figure 39: Human motion simulation within a workplace using Delmia's Virtual Manufacturing solution

A Delmia's Virtual Manufacturing solution from Dassault Systemes Company called Ergoplan (new released version, Delmia Process Engineer) was utilised to design and improve the manual workplace. A part of this software system (optional) provides a tool, which improves the work sequences in predominately manual workplaces. This tool makes it possible to design the motion sequences of the worker in the workplace, to analyse with the aid of realistic motion simulation and to improve them according to fundamental principles of motion economy and ergonomics.

Figure 39 depicts a screen shot of the human simulation using the software tool. Method Time Measurement (MTM-I) notation, used in the definition of the motion sequences, is simulated along with the graphical user interface in teach-in mode. The fields of vision and reach ranges can be represented in accordance with the relevant model and the current body posture. During the simulation of movement sequences, the forces and torque on each individual joint are automatically charted in graphical form. Analysis works with respect to the evaluation of ergonomic parameters such as stress of the current posture can also be performed. This simulation tool enables the planner to detect and avoid ergonomic problems in the earliest stages of the workplace design, which normally become apparent during the implementation phase. In this work, the evaluation and improvement of a manual workplace, where a manual lifting task takes place, is considered as a case study for the application of human motion simulations.

4.2.3 Implementation of Human Simulation in the Manual Workplace

One of the most common physical tasks performed by humans in the workplace is lifting. Back injuries are the most common injuries reported as a result of work surface too low, load slightly out of reach or incorrect lifting. When performing a manual work, loads may be lifted to reach or over-reach heights. The variables associated with lifting to reach and over-reach heights play an important role in the worker's ability to accomplish a given task.

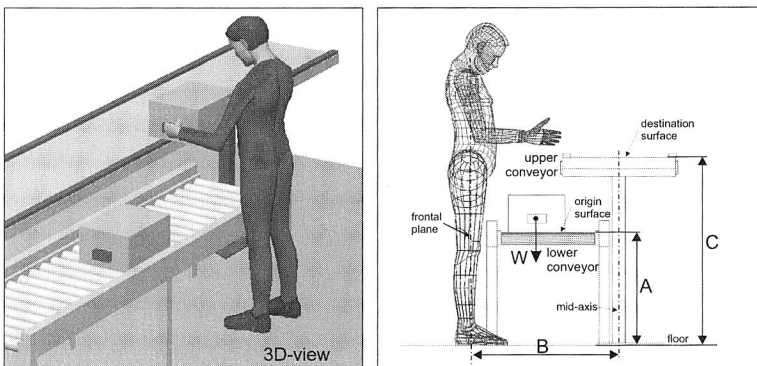


Figure 40: Manual lifting task with design parameters

Figure 40 depicts the workplace that has to be analysed. The lifting operation begins with reaching the bin, picking it up and placing it in the belt conveyor. The parameter to be considered is the height of the low conveyor (A), the height of upper conveyor (C) and the horizontal distance between worker's and upper conveyor's frontal plane (B). The values of these parameters for both initial and improved workplace design as well as the weight of the bin are shown in Figure 41. The lifting task with 50th percentile male has been simulated by using the functions from the software tool, described in the previous section. The results are (1) the required time doing the task, (2) postures assessment, (3) moment-time-diagram for several joints, and (4) the generated MTM-codes for each movement sequence. For the initial workplace design, R45B, M45B and M41B MTM-codes are generated during simulation, which is a total of 51,4 TMU and two postures are stressing at the end of step 1 and 3.

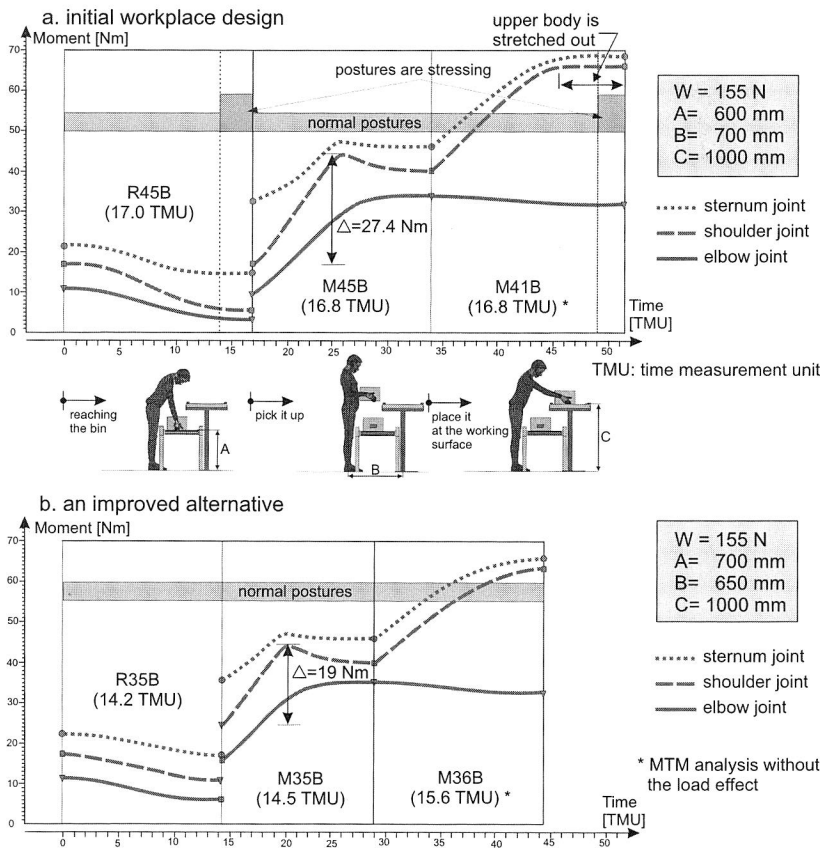


Figure 41: The result of human motion simulation during a manual lifting task from two workplace design alternatives

The necessary improvement measures for the workplace based on the simulation results focus on eliminating poor postures, achieving a better motion economy and reducing work fatigue. The improved workplace design with the new dimensions shown in Figure 41 (bottom) shows new simulation results. The required time for doing the task has been reduced to 44,3 TMU (14%) and the poor postures have been eliminated. Another important result is that the upper body postured is bent less than 20° forward. In addition, the difference between maximal and minimal moment values in sternum and shoulder joints during the 2nd step is also reduced to 31%. This has a positive impact on the work fatigue and energy expenditures.

4.3 A Combined Approach for Improvement of Manual Workplaces

This approach combines the video aided assembly task analysis with the Virtual Manufacturing approach for improvement of manual workplaces. The measures for the manual workplace include both the improvement of the human assembly task from ergonomic point of view and the time reduction. This approach is particularly utilised for evaluating and redesigning current workplaces and is based on the practical experience in industrial manufacturing.

Macro analysis e.g., system layout, product profile (production volume of each variants based on recent history) and production flow analysis should be taken into account, when improving ergonomics and process flows in the manual assembly workplace. Several data are required for the improvement measures, total worker involved, daily production, number of variants or number of shift work. Macro analysis will submit the results of the improved process flows based on product families, of the average lot sizes per order and of the efficient macro-layout. After considering the macro level, the improvement measures of the production and assembly systems should be conducted at cell or workplace level using the proposed approach.

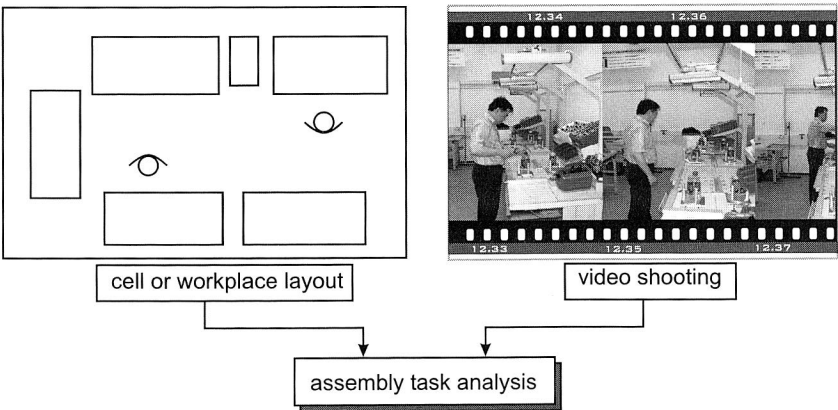


Figure 42: Data collection for assembly task analyses

The first step is the collection of input data for assembly task analyses (see Figure 42). The activities performed in each assembly sequence in the workplace are recorded on video. Subsequently, the graphical representation of the workplace layout should be drawn. Other data included explanatory variables like part weight, distance between two closest sequences, work surface or crane speed have to be collected during video-shoot.

The next step is the evaluation of the current situation on process flow as well as the ergonomic aspects. First, the process flow data on the video record has been documented by using a time a study sheet in the Microsoft Excel according to REFA standard [129]. In this sheet, each process segment or activity has been observed individually and categorised based on the worker's activity (see Figure 43). Thus, elapsed time is noted progressively as each process segment is completed.

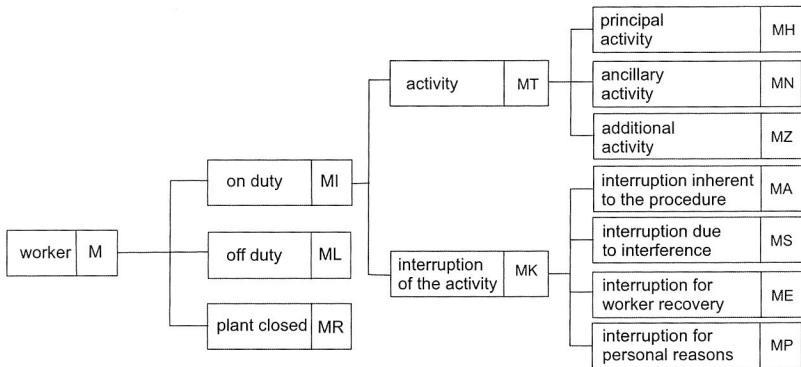


Figure 43: Categorising the types of processes in term of the worker's activity [129]

Requiring a minimum of time and effort, a work sampling observation using video record produces an accurate reflection of the current conditions. A diagram for every assembly sub-task can be created, based on the result of the time study sheet in the previous step. The diagram shows the proportion of times spent in principal activities, ancillary activities, additional activities (e.g. geometric measuring) or interruptions inherent to the procedure observed in the workplace. This diagram is an important data for current evaluation on process flow aspect. This data can be used as starting information for creating some possible alternative improvements. Based on practical approach, improving the process flow in order to reduce lead time can be achieved by following alternatives: (1) considering the product assembling characteristic, e.g. changing the product structure using subassembly, (2) technology approaches (e.g. using better assembly tools or standard parts that reduce assembly operations), (3) improved layout design according to motion economy principles. The last one can be virtually performed by using Virtual Manufacturing software.

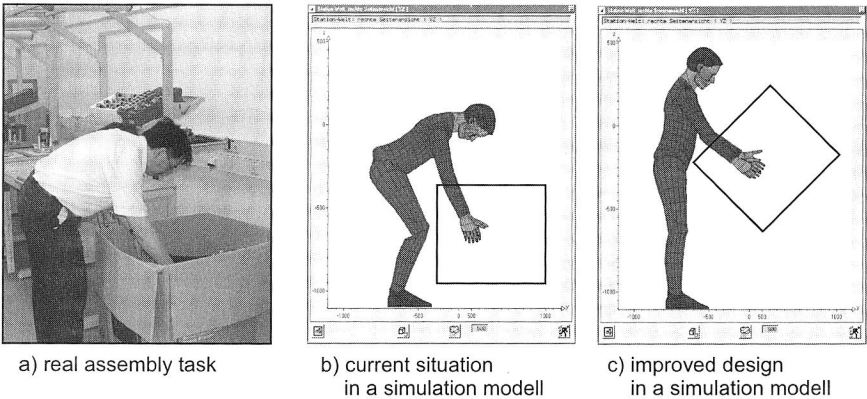


Figure 44: Frequent bending during assembly tasks and improved design in the simulation model

Thus, the evaluation of the current situation from ergonomic aspects can be performed. The graphical representation of the major facilities as well as the layout should be delivered into digital forms in the software. Using this Virtual Manufacturing approach along with information of assembly task from video record, the ergonomic aspect can be virtually simulated and identified. The awkward postures while doing certain tasks can be virtually simulated and identified. The Virtual Manufacturing software allows generating many possible improvement alternatives. Subsequently, several alternative workplaces can be evaluated and heuristically improved by means of virtual models along with simulating a human model while performing the task. Figure 45 shows this combined approach for improvement of a manual workplace from the ergonomic aspects.

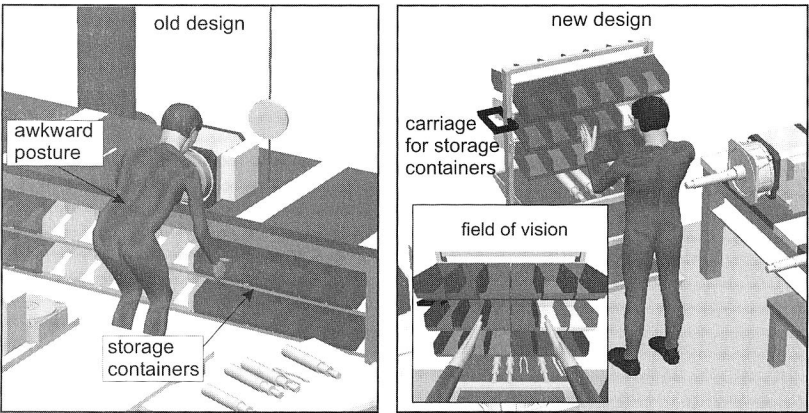


Figure 45: The old and new design of a manual assembly workplace using the combined approach

Figure 45 depicts an old and a new design of a manual assembly workplace using the Virtual Manufacturing combined with the video aided assembly task analysis. This approach improves a manual workplace for assembling electric motors. The evaluation of the old manual assembly workplace shows that the principal activities have only 30% from the worker's total activities. The rest activities are related with the ancillary and additional activities as well as the interruption activities inherent to the procedure. From an ergonomic point of view, the layout of the storage containers and assembly tools is also disadvantageous. The new assembly workplace has been designed by using this approach. The new design of the manual assembly workplace is considered for extreme small lot size. It has a compact and efficient layout in order to ensure the smooth flow of materials. The interruption activities inherent to the procedure in the new design can be eliminated by means of changing the product structure. The ancillary activities, related to the preparation of screwing operations as well as human motions in the workplace, can be shortened. Furthermore, a new carriage for storage containers has been constructed to store the small parts (e.g. bolt, nut, washer, key, etc.) for certain product families. This new design is improved from ergonomic aspects, especially due to the reduction of the poor postures. It generally brings an improvement for both process flow and ergonomic aspect.

5 Internet-based Collaborative Virtual Environments and its Corresponding Technologies

The trend towards globalisation also leads to increasing collaborative working environments for the parties involved. Working in multidisciplinary teams along with information sharing and exchange of ideas in different locations requires adequate methods and tools. With the increasing ubiquity of the Internet and its corresponding technologies, several novel techniques can be used to deploy the internet-based collaborative environments, particularly in connection with specific technologies for displaying and exploring Web contents in three dimensions. Therefore, Chapter 5 gives a state of the art overview of the Internet-based environments and its corresponding technologies in order to systematically develop such collaborative virtual environments for planning of assembly systems over the Internet.

5.1 Basic Principle of Modern Internet Technologies

The Internet is a massive network of networks, a networking infrastructure. It connects millions of computers globally, forming a network in which any computer (also known as host) can communicate with any other computer as long as they are both connected to the Internet. The information travels over the Internet in a variety of languages known as protocols, e.g. TCP/IP [72].

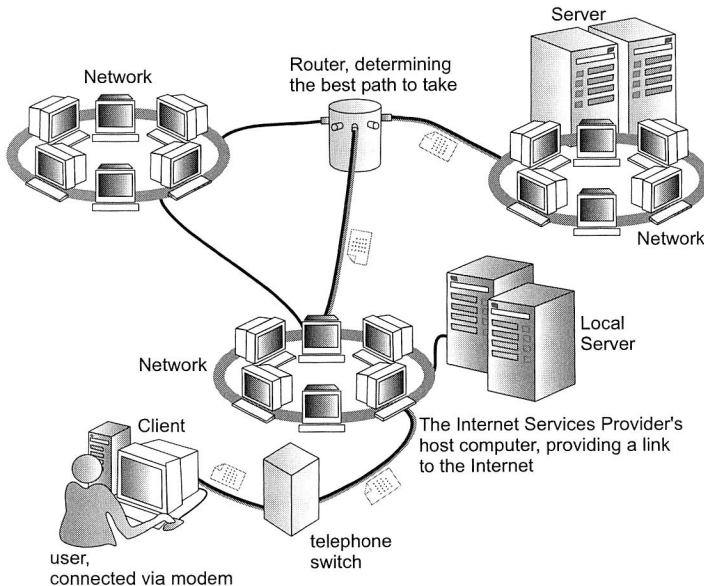


Figure 46: Messages over the Internet, considering as an example of network communications

When shrunk down to its essence, the Internet is very similar to a local-area network. Communication over the Internet is roughly the same as communication over a client/server network. The user as a client sends messages and requests to the server, and the server fulfils the requests and sends back the results. The difference between them is that in the Internet the server can be very far away from the client and the messages can go through different networks. Since the Internet is an immense network of networks that connects millions of computer users, the messages passed through the Internet must be navigated so that they reach their destination.

Figure 46 shows that the client typically connects to the Internet by calling the host computer of the Internet Service Provider (ISP). This computer is directly hooked up to the Internet, thus it is actually the real client. From here, the client's message may pass through another separate network, or go through a router, which determines the message's destination and the best path for the message to take, based on network traffic and connections. As the message goes through different networks, protocols aboard servers convert the message into packets. These packets contain destination information, data size or error-control data. When the server receives the packet, it reads the message and fulfils the request and returns a file back to the client. It often replies to the client stating that it has completed the request.

5.1.1 Distribution of Internet and its Potential

The Internet is a powerful, ubiquitous, relatively inexpensive and robust communications mechanism. However, some issues like security, capacity or bandwidth still concern the researchers. As open system architecture, the Internet has become a medium of commerce, marketing and education activities as well as a medium for research, engineering or medicine, etc.

Figure 47 depicts the distribution of the medium Internet in Germany. In Germany, in 2003, there were identified about 34,5 Million Internet users⁹ (equivalent to over 50% of the Germans, age 14+). The distribution of the Internet can also be measured by the development of the number of Internet hosts. Worldwide, based on the surveys of the Internet System Consortium [109], the number of Internet host computers has been growing at an enormous rate. Spread of Internet application in e-commerce for instance has undoubtedly been the advent of the information richness of the Web. Forrester Research [119] predicts that by 2004, online commerce will reach \$6.8 trillion. This huge amount comprises Forrester's projection for both business-to-business and business-to-consumer transactions online. In Germany itself, online commerce reached about \$386.5 billion in 2004, that's the equivalent of 5,7% of the world's e-commerce.

⁹ The Internet user is defined as person who used the Internet at least once in last 12 months, with a kind of services such as: Web, E-mail, FTP or Newsgroup.

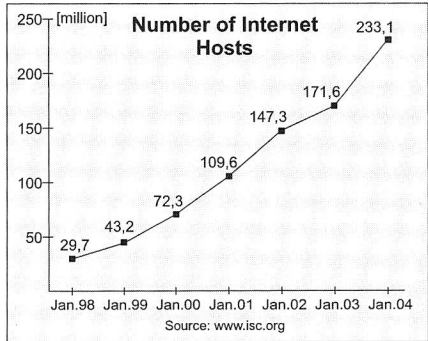
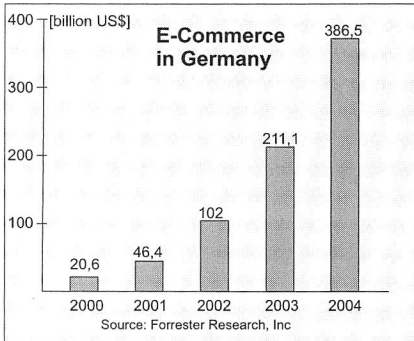
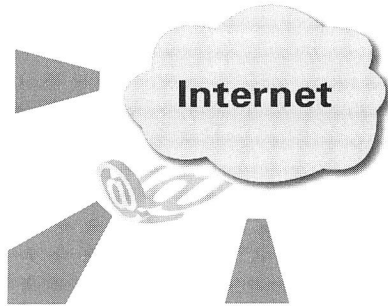
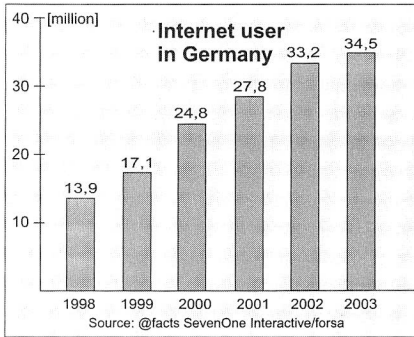


Figure 47: Distribution of Internet and its potential

The Internet has changed the way of communication, work, play, live and to do business. It has the potential to provide billions of people with access to information, services and products as well as sharing and collaborate on them. The particular potentials of the Internet medium are related to its characteristics such as interactivity of the medium, multi-medial presentation, multi-functionality, accessibility of information and availability of Internet contents at any time and in any place (illimitability).

5.1.2 Networking and Protocol

To connect hosts on the Internet, a number of communications protocols is used. In this case, a protocol consist in the rules and conventions used in inter-process communication that govern the formats of data exchanged, the structuring of the dialogue and the handling of exceptional circumstances. TCP/IP, abbreviation for Transmission Control Protocol/Internet Protocol uses several protocols, the two main ones being TCP and IP. The two protocols are a larger set of software programs that provide network services such as remote logins, remote file transfers and electronic mail. TCP/IP provides a method for transferring information from one machine to another. This protocol should

handle errors in transmission, manage the routing and delivery of data and control the actual transmission by using predetermined status signals.

TCP/IP is based on a four-layer reference model. All protocols that belong to the TCP/IP protocol suite are located in the top three layers of this model. As shown in Figure 48, each layer of the TCP/IP model corresponds to one or more layers of the seven-layer Open Systems Interconnection (OSI) reference model proposed by the International Standards Organization (ISO). The OSI reference model is not specific to TCP/IP. It was developed by the ISO in the late 1970s as a framework for describing all functions required by an open interconnected network. It is a widely known and accepted reference model in the data communications field and is used here only for comparison purposes. The types of services performed and protocols used at each layer within the TCP/IP model are described more detailed in Table 1.

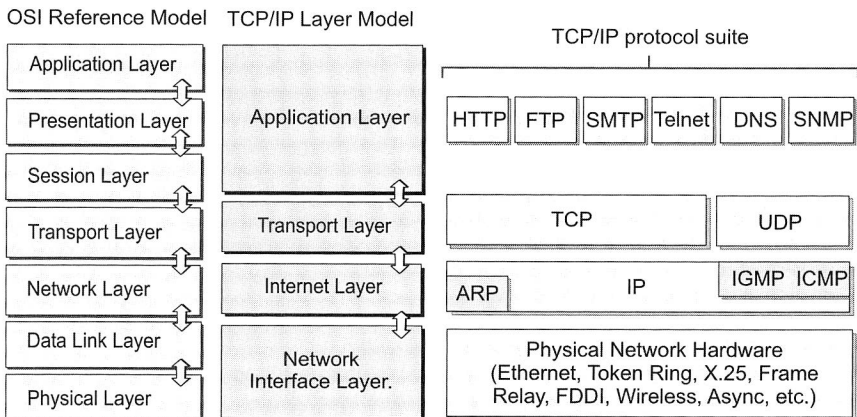


Figure 48: OSI Reference Model and TCP/IP Protocol [120]

An identifier for a computer or device on a TCP/IP network is called IP address. Each computer must have an IP address before it can connect to the Internet. The networks using the TCP/IP protocol route messages based on the IP address of the destination. The format of an IP address version 4 is a 32-bit numeric address written as four numbers separated by periods to address a computer. Each computer (host) must have a unique 4 number address. For example, 131.188.113.106 is an IP address for the Web server of the Institute of Production Automation and Production System (FAPS) University Erlangen-Nuremberg. Furthermore, future IP addressing scheme using 128 bits, called IP version 6, has been developed to provide multicasting and a better quality of service [2].

Layer	Description	Protocols
Application	Defines TCP/IP application protocols and how host programs interface with transport layer services to use the network.	HTTP, Telnet, FTP, TFTP, SNMP, DNS, SMTP, X Windows, other application protocols
Transport	Provides communication session management between host computers. Defines the level of service and status of the connection used when transporting data.	TCP, UDP, RTP
Internet	Packages data into IP datagram, which contain source and destination address information that is used to forward the datagram between hosts and across networks. Performs routing of IP datagrams.	IP, ICMP, ARP, RARP
Network interface	Specifies details of how data is physically sent through the network, including how hardware devices that interface directly with a network medium, such as coaxial cable, optical fibre or twisted-pair copper wire.	Ethernet, Token Ring, FDDI, X.25, Frame Relay, RS-232, v.35

Table 1: The types of services performed and protocols used at each layer within the TCP/IP model [120]

5.1.3 World Wide Web

The World Wide Web, or simply “the Web”, provides a uniform user-friendly interface to the Internet. Web pages can contain text and pictures or other multimedia contents, interconnected by hypertext links. The addresses of Web pages are recorded as Uniform Resource Locators (URLs), transmitted by Hypertext Transfer Protocol (HTTP) and written in Hypertext Markup Language (HTML). Programs that allow using the Web are available for most operating systems.

The World Wide Web started out in 1980 at CERN (the European Laboratory for Particle Physics). A researcher named Tim Berners-Lee created a program called “Enquire-Within-Upon-Everything” to keep track of randomly associated documents by linking them together [38]. In 1989, Berners-Lee proposed a global extension of his ideas that would link hypertext documents all over the world [19]. The content would be put on servers and people would use browsers to view it. However, the Web was catapulted to success only with the release of Macintosh [96] and Windows [113] versions of Marc Andreessen’s World Wide Web client program (Web browser), called Mosaic in 1993. One year later, Andreessen started Mosaic Communications, now called Netscape [38]. Since then, the Web has shown astonishing exponential growth.

Nowadays, there are several applications called Web browsers that make it easy to access the World Wide Web. The most popular Web browsers are Microsoft Internet Explorer, Mozilla and Netscape Navigator.

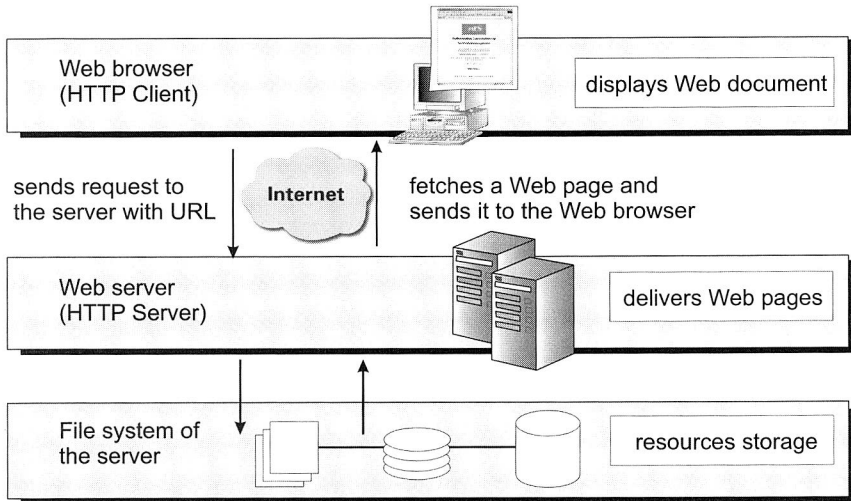


Figure 49: Fundamental concept of the World Wide Web [55]

In principle, the World Wide Web bases on the following fundamental concept (see also Figure 49):

- **Hypertext Markup Language (HTML)** is a language used to create hypertext documents for use on the World Wide Web. The hypertext concept is a way of presenting information in such a way that the sequence of the information is left up to the reader. The hypertext works by means of hyperlink, which are highlighted or underlined words (or graphics) that one can click to bring another document into view.
- **A Web browser** is a software application used to locate and display Web pages. The Web browsers can display graphics as well as text. In addition, most modern browsers support Java and JavaScript and they can also present multimedia information, including sound and video, though they require plug-ins for some formats.
- **A Web server** is a computer that delivers (*serves up*) Web pages. Every Web server has an IP address and possibly a domain name. A Web browser can send a request to the server and the server then fetches a page, names and sends it to the browser.

- **Uniform Resource Locator (URL)** is the global address of documents and other resources on the World Wide Web. The first part of the address indicates what protocol should be used; the second part specifies the IP address or the domain name where the resource is located and the rest of the parts indicate the path and the resource name. Figure 50 provides a graphical explanation of URL.

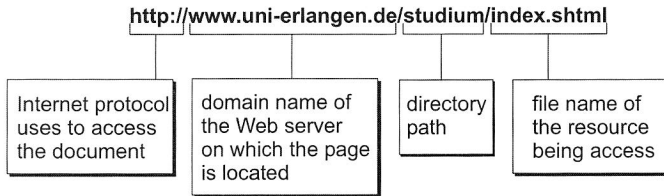


Figure 50: Structure of URL

5.2 The Client-side Web Technologies

Client-side technologies for the Web are those, which are interpreted and executed by the user's browser. So basically, using a browser, a Web site address will be sent in order to make a request to the Web server where the HTML files are stored and the HTML file is sent to the browser for viewing. The different technologies that are included in the HTML pages like CSS or JavaScript are all executed on the client's browser. It may happen that the client-side technologies are not fully supported by the browser, thus the Web page will display incorrectly. Client side codes, by their nature, are also visible to anyone accessing the Web site, which makes it unsuitable for security functions.

In this work, the design and development of a Web-based environment for collaborative planning of assembly systems utilises several client-side Web technologies. These technologies are used to equip some aspects of the prototype software such as interactive Web pages, formulas and operations, data management over the Internet and three-dimensional representations of production systems into Web pages. These include the use of HTML, DHTML, XML, DOM, JavaScript/JScript, Plug-in/ActiveX Control as well as VRML in Web development.

5.2.1 Markup Languages for the Web

A markup language is a collection of elements that are used to indicate the structure and format of a document. Marked-up documents are interpreted by computer software to display or print their contents. Documents can easily be exchanged between computer systems with software that can interpret the markup language used.

Markup was specific to the software package used, so if a document was transferred to a different software package then the markup of the document needed to be converted

into a kind of markup that the other system understood. This could have been a particular problem with different file formats. Additionally, the markup was largely related to the appearance of a document.

Standard Generalised Markup Language (SGML), standardised by ISO 8879 [110], is a language used to define markup languages. HTML itself, as a language for document used on the Web, is an application of SGML.

Standard Generalised Markup Language (SGML)

SGML is a meta-language and it enables to define mark-up languages (SGML applications) by defining valid document structure using a Document Type Definition (DTD). An SGML application consists of an SGML declaration, which specifies the application's characters and delimiters, a DTD, which may also contain character entity references and other definitions, a semantic specification that captures meaning and syntax restrictions that cannot be described in the DTD and a collection of document instances.

Content in SGML is information, which includes paragraphs, headers, tables, lists, graphics, etc. Moreover, tags define the position of contents within a document. Documents are described using a hierarchic model where each element is placed in a well-defined logical tree structure. SGML enables the creation of well-structured documents that are portable and are both, hardware and software independent. Since HTML is an application of SGML, elements and attributes of SGML applications have syntax similar to HTML.

Hypertext Markup Language (HTML)

HTML is the *lingua franca* for publishing hypertext on the Web. It is a non-proprietary format, based upon SGML, for describing the structure of hypermedia documents - plain text (ASCII) files with embedded codes for logical markup, using tags like <A> and to structure text into tables, hypertext links interactive forms, headings, paragraphs, lists, and more. HTML is used to publish documents on the Web as well as to define the structure of documents and links between them. The language is constantly undergoing revision and evolution to meet the demands of the growing Internet community under direction of the World Wide Web Consortium (W3C)¹⁰, the organisation that coordinates HTML standard.

HTML standards created by W3C, such as HTML 2.0 [18], HTML 3.2 [128] until HTML 4.01 [131], allow the creation of Web sites with a rich mix of text, graphics and multimedia using a set of elements and entities as defined. Each version supports more options than the previous versions. The latest version, HTML 4.01, supports more multimedia options, scripting languages, style sheets, better printing facilities and documents that are more accessible to users with disabilities.

¹⁰ The World Wide Web Consortium (W3C) is an industry consortium, which develops interoperable technologies (specifications, guidelines, software, and tools) to lead the Web, to its full potential.

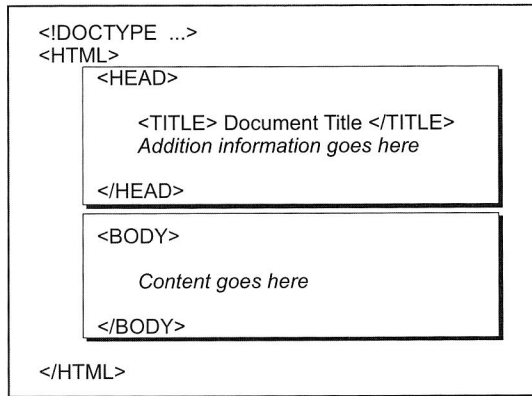


Figure 51: An HTML 4.01 document structure

An HTML 4.01 document structure as shown in Figure 51, is composed of three parts namely a line containing HTML version information, a declarative header section and a body. The body may be implemented by the BODY element or the FRAMESET element.

Extensible Markup Language (XML)

One of the most significant new Web standards to emerge recently is XML, the Extensible Markup Language. XML defines a standard format for representing and exchanging structured data on the Web, enabling the use of standard APIs (Application Programming Interfaces), DOM (Document Object Model) for managing that data and the deployment of standard services for generating and viewing XML content. XML has already been widely adopted by an industry eager to overcome the limitations of HTML for structured data. XML is expected to become a standard means for delivering database-driven Web content and already serves as the basis for a variety of Web applications, from metadata representation to domain-specific markup languages.

XML is a Web-efficient subset of SGML and intended to eventually replace HTML. It is a project of the World Wide Web Consortium (W3C). The development of the specification is being supervised by the XML Working Group. A recent development that W3C in [26] has endorsed is XML 1.1. This markup language is more flexible than HTML, because authors can define their own tags/elements and attributes which are easy to read for machines and humans and describe the content accurately. The custom-defined XML tags thus enable the generation of domain specific markup languages for diverse fields, such as vector graphics, mathematics, music and technical documentation [144].

As XML data is in text form, it is portable across a number of platforms and environments. The original source document can be displayed on a computer monitor, within a

cellular phone display or translated into voice. The potential of XML formatted data has enabled various groups to create their own domain specific markup languages.

The Extensible Hypertext Markup Language (XHTML)

Most current W3C recommendation for hypertext implementation has been represented by XHTML [125]. It merges the Extensible Markup Language (XML) technology with the HTML 4 standard to create a very flexible language that sets the framework for future Web page development. XHTML is HTML expressed using XML. The old HTML standards will still work in Web browsers, but Web developers can now use the new XHTML standard to write Web pages that can integrate well with other technologies defined by XML.

5.2.2 Client-side Programming for the Web

A Web application describes a broad range of software that adds dynamic functionality to Web sites. Web programming enables a wide variety of features from the basic to highly complex, i.e. real-time stock trading and online banking. Programming categories for Web applications include client-side and server-side programming. As Web server executes a server-side programming that, client-side programming in contrast describes codes or scripts. Thus, the Web browser executes these programs. Client-side programs are associated with Web pages, which are downloaded by the client from the server and then executed locally on the client's computer.

A Web-based approach for collaborative planning of production systems over the Internet as a Web application consists of several Web pages, which are executed by a Web browser, e.g. Microsoft Internet Explorer. The client-side software is embedded in HTML documents in Web pages to achieve the required functionality by the application.

The following codes or scripts are some common types of client-side programming for Web:

- JavaScript and JScript
- Java applet
- Plug-in scripting

JavaScript and JScript

JavaScript [53], [61] is a powerful scripting language that can be embedded directly in HTML. It allows creating dynamic, interactive Web-based applications that run completely within a Web browser. Using JavaScript, robust and complete Web applications can reasonably be written. However, JavaScript is not a substitute for Java, but it is a good client-side complement to Java. Using them concomitantly allows creating more complex applications than only with JavaScript.

Netscape Navigator, beginning with version 2, first implemented this scripting language. Subsequently, Microsoft Internet Explorer also supported this scripting language, beginning with version 3. The Microsoft version has its own name, called JScript. Then, this scripting language was endorsed by a number of software companies and now it is an open language that anyone can use without purchasing a license.

JScript is Microsoft's extended implementation of ECMAScript [105], an international standard based on Netscape's JavaScript and Microsoft's JScript languages. JScript is implemented as a Windows script engine. This means that it can be plugged-in to any application that supports Windows script, such as Internet Explorer, Active Server Pages (ASP) and Windows Script Host.

Within a Web application in this work, JScript is used for both simple tasks such as mouseovers on Web pages and for more complex tasks such as accessing document object in form of Internet Explorer's Document Object Model (DOM) or calculating of user-inputted parameters from several checklist forms.

Java Applet

A Java applet is a small compiled program application written in the Java™ programming language that can be included in an HTML page, in the same way as an image is included. When a Java technology-enabled browser is used to view a page that contains an applet, the applet's code is transferred to the system and executed by the browser's Java Virtual Machine (JVM). Traditionally, the inclusion of a Java applet in an HTML document has been done via the applet tag `<APPLET> ... </APPLET>` with appropriate attributes. According to the current HTML 4.0 specification [127], this tag has been deprecated in favour of the more generalised `<OBJECT>` element.

Java applets allow the power of a true programming language to be executed on the client-side. A distributed computing, a platform-independent solution as well as an interactive Web page are some of the important issues in the Java applet. A Java-enabled Web browser offers the basic infrastructure needed to integrate computers connected to the Internet into a seamless parallel computational resource and distributed applications. Java applets are designed to be platform-independent and can also be used on any machine running a version of the Virtual Machine. It allows Java applets to be run on several machines at the same time. Beside distributed applications and platform-independence, interactive Web page such as animations, sounds, real-time interactions, data manipulations and database applications can also be implemented in Java applets and add new levels of functionality to Web sites.

Plug-in Scripting

A plug-in extends the abilities of a Web browser. It is small software that allows browsers to display or execute additional files and native to the specific platform on which the Netscape Communicator runs. Popular plug-ins enable a browser to display animations, play audio and video or visualise virtual objects.

The term embedded object is typically used synonymously with plug-in. However, technically an embedded object is any page element that is not standard HTML/XML, Web graphics or other native Internet files. The line between the two has become blurred as browsers evolve. What was once a plug-in became a built-in feature. For example shockwave/flash used as a plug-in has become increasingly popular, so that many browsers now include this function in the off-the-shelf package.

Plug-in scripting is a general term to describe any programming that is contained in an embedded page object. The example of object scripting utilised in this work is Parallel-Graphics Cortona® Software Developer Kit [98], which provides scripting Application Programmable Interfaces (APIs) that allow manipulating 3D models embedded in a Web application. These capabilities have been used on development such as a Web-based assembly planning systems.

5.2.3 Other Client-side Web Technologies

Besides markup languages and client-side programming for the Web, other client-side Web technologies have been utilised on the development of a Web-based environment for collaborative planning. They include CSS, DHTML, DOM, ActiveX technology and cookies. A short explanation of those client-side technologies will be provided in the following section.

ActiveX Technology

ActiveX technology is a loosely defined set of technologies developed by Microsoft. This technology can be compared with another similar embedded object technology, called plug-in technology, which was developed by Netscape. ActiveX is an outgrowth of two other Microsoft technologies called *OLE (Object Linking and Embedding)* and *COM (Component Object Model)*. This technology is used to add interactivity to Web pages. As a moniker, ActiveX applies a whole set of COM-based technologies.

Another closely associated term is ActiveX controls, which represent a specific way of implementing ActiveX technologies. This control can be automatically downloaded and executed by a Web browser. Programmers can develop ActiveX controls in a variety of languages, including C, C++, Visual Basic and Java.

An ActiveX control is similar to a Java applet. Unlike Java applets, however, ActiveX controls have full access to the Windows operating system. This gives them much more power than Java applets, but with this power comes a certain risk that the applet may damage software or data on your machine. To control this risk, Microsoft has developed a registration system so that browsers can identify and authenticate an ActiveX control before downloading it. Another difference between Java applets and ActiveX controls is that Java applets can be written to run on all platforms, whereas ActiveX controls are currently limited to Windows environments. Table 2 shows the comparison between plug-in, Java applet and ActiveX technology.

	Plug-in	Java applet	ActiveX
Platform-independent	No	Yes	No
Risk for client programs	Yes	No	Yes
Downloads on the fly	No	Yes	Yes

Table 2: The comparison between plug-in, Java applet and ActiveX technology

More application using ActiveX control in order to interface VRML scenes from external application in Web browser will be discussed in the section 7.2.1.

Cascading Style Sheet (CSS)

A Cascading Style Sheet (CSS) is a stylesheet language for HTML and XML documents that controls their layout and formatting. The Cascading Style Sheet, level 1 (CSS1) and level 2 (CSS2) recommendation from the World Wide Web Consortium [23], is implemented in the latest versions of the Netscape and Microsoft Web browsers and specifies the possible style sheets or statements that may determine how a given element is presented in a Web page.

The idea of CSS is a clearly separation of the content of an HTML document from the document's presentation layout. To solve this problem, the STYLE element has been created in addition to HTML 4.0. Styles define how HTML elements are displayed, just like the font tag and the colour attribute in HTML 3.2. Styles are normally saved in files external to the HTML documents. External style sheets enable to change the appearance and layout of all the Web pages, just by editing a single CSS document. In Web design, CSS is a breakthrough because it allows developers to control the style and layout of multiple Web pages. In this work, the CSS is one of the instruments to control the appearance of Web pages.

Dynamic Hypertext Markup Language (DHTML)

Dynamic HTML is the art of combining the client-side technologies of HTML, CSS and JavaScript in order to create dynamic and interactive Web pages. It adds richer, more engaging user interfaces to the HTML presentation language while greatly reducing the workload of networks and servers. The object model provided by Dynamic HTML gives Web developers the ability to dynamically update the content, style and structure of Web-based content, while providing them with detailed control over the appearance, interactivity and multimedia elements required for a polished and exciting application.

Developed in collaboration with the World Wide Web Consortium (W3C), Dynamic HTML is a feature of the Microsoft Internet Explorer (IE4+) as well as Netscape Navigator (NS4+). These two major browsers share the same concept but they use slightly different ways to accomplish it. Netscape offers <LAYER> tag incorporated with

JavaScript and Style Sheets while Microsoft uses ActiveX and CSS Style Sheets incorporated with scripting language like JScript or VBScript.

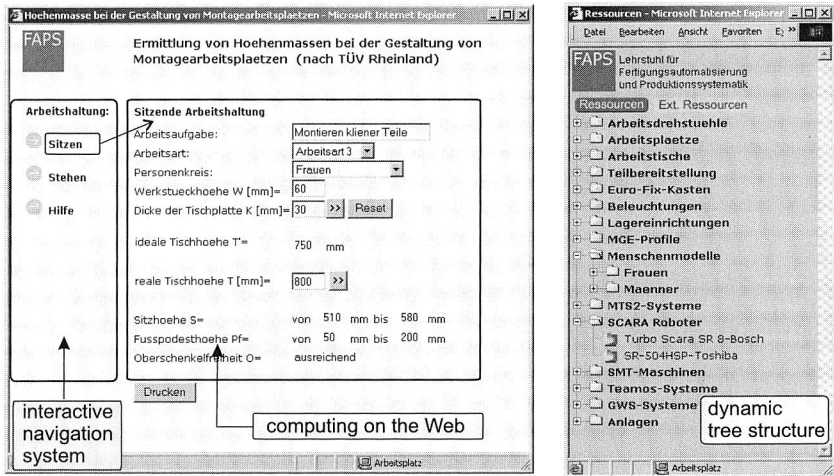


Figure 52: Applications of dynamic HTML

Figure 52 shows some Web applications created in this work, utilising the concept of dynamic HTML. The left figure depicts the application of dynamic HTML concept to compute on the Web, using formulas with a navigation system. The other figure presents a dynamic tree, which organises information in a tree layout, allowing the user to navigate the tree, expand and collapse tree branches.

Document Object Model (DOM)

The Document Object Model (DOM) is an application-programming interface (API) for valid HTML and well-formed XML documents. It defines logical structures of documents and the way a document is accessed and manipulated. In the DOM specification, the term "document" is used in the broad sense. However, XML is being used increasingly as a way of representing many different kinds of information that may be stored in diverse systems, and much of this would traditionally be seen as data rather than documents. Nevertheless, XML presents this data as documents and the DOM may be used to manage the corresponding data [64].

Using the Document Object Model, programmers can build documents, navigate their structure as well as add, modify or delete their elements and contents. Anything found in an HTML or an XML document can be accessed, changed, deleted or added using the Document Object Model.

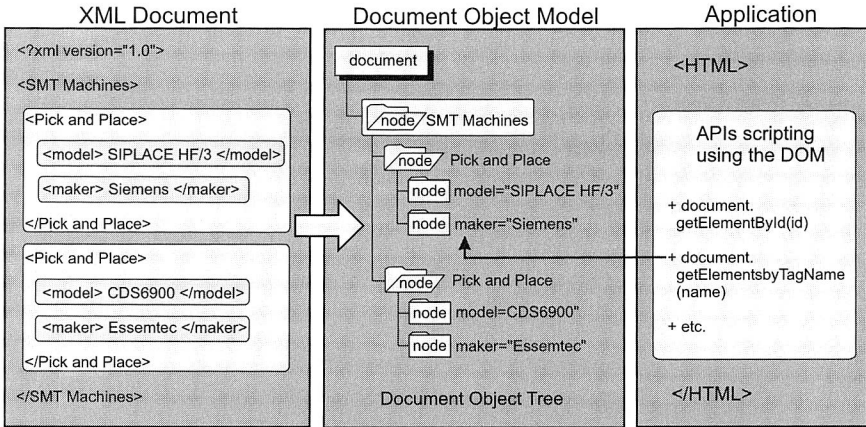


Figure 53: A tree-like structure in DOM enables a Web application accessing the elements of an XML document

A DOM is separated into three parts namely the Core, the HTML and the XML DOM. The Core DOM provides a low-level set of objects that can represent any structured document. While this interface is capable by itself to represent any HTML or XML document, the core interface is a compact and minimal design for manipulating the document's contents. Depending upon the DOM's usage, the core DOM interface may not be convenient or appropriate for all users. The HTML and XML specifications provide additional, higher-level interfaces that are used with the core specification to provide a more convenient view into the document. These specifications consist of objects and methods that provide easier and more direct access into the specific types of documents.

Figure 53 shows a typical example to demonstrate, how the Document Object Model as one of client-side technology can be employed to process XML data (it will be explained in greater detail in the section 7.2.5). It provides tree-like structures that enable a Web application programmatically access to the components of an XML document. Using a DOM-supporting programming language, such as JavaScript DOM API, make it possible to manoeuvre within the XML data in order to perform queries, processing or modifications.

5.3 Collaborative Virtual Environments for Production Systems Planning

A virtual environment is a synthetic computer generated representation of a physical system [68]. Using these virtual environments as a user interface to support human-human communications is a basic idea of a collaborative virtual environment. The system is designed to support location-independent shared analysis of spatial data and

visualisation. It seeks to extend the physical workplace of the participants into the virtual environments, while preserving traditional textual and verbal communication and cooperation mechanisms [91]. The potential of collaborative virtual environment technology is widely acknowledged with a variety of organisations and institutions increasingly finding new and innovative uses for this technology. These uses encompass the fields of design and planning, entertainment, medicine and engineering [28], [56].

The Internet is an ultimate collaborative environment, allowing the digital information to be shared instantly and globally among related parties. Data will be used and re-used to reduce development times and costs further on and simultaneously improve product quality and maintainability. A virtual environment over the Internet enables an online world integrating real-time 3D graphics, rendering and visualisation as well as the information exchanges. People in remote sites meet in a collaborative virtual environment to discuss, view and manipulate digital information as well as to plan and design by means of 3D graphic objects.

5.3.1 Conceptual Foundation

The conceptual foundation for the Internet-based virtual collaborative environments for production system planning consists of the users, the planning process they do, the data they need and/or create, and the tools and services they use or provide.

The Users

There are several groups of users that will be meeting on the platform. They may include:

- Traditional project participants that would typically be involved in the designing or planning processes. This would include several engineers with different core skills, project managers or other related participants
- The client or the owner of the planning project
- Providers of knowledge, services and tools who use the platform to sell their expertise

The Planning Process

The planning process is a series of activities, involving some resources and methods, conducting to a result. For instance, planning processes of assembly systems are initiated by product data. The actual product to be manufactured will dictate the required facilities, equipment, personnel, and processes to be used. The more complex the item to be manufactured is, the more people will be likely to be involved in the planning process and the more meetings will be held. The main focus of the planning process in this work is the planning of production facilities, particularly in the assembly systems. They can consist of several elements and levels. According to [160], the top level in the hierarchy is a factory and which divisions, production or assembly lines, stations and re-

sources follow. The resources, as the lowest level in the hierarchy, include machines and other facilities, area, personnel, material as well as information. Each level considers a specific planning task. For instance, line level planning deals with material flows and line layouts, while station level planning concentrates on the workplace design and design of assembly operations.

The Data

The required data from each level of planning of production and assembly systems is different. Product and order data are primary data for planning activities. Other data include technical data like line structures, manufacturing, material flow and break down data as well as organisation data like working times, shift models or resources allocations. Consideration of data quality during planning processes should be paid special attention in order to obtain a good result. In addition, the planning data in form of three-dimensional solid models with their corresponding information are increasingly used, particularly for planning approaches like Digital Factory [21] or Virtual Manufacturing [49]. In this work, for instance, tree-dimensional models based on VRML (Virtual Reality Modelling Language) represent the products or resources geometry data.

Tools and Services

Tools and services support or enable the communication and the planning process activities. For Internet-based virtual collaborative environments, they include:

- Software, either to be installed on the client's machines, or to be dynamically loaded through the Internet. The communication supports such as email, video conferencing and other collaboration tools e.g. NetMeeting are parts of required software.
- Infrastructure services that do not generate or influence the design and planning data.
- Databases that provide access to the data types e.g. resources model database
- Help desk, discussion forum and related FAQs

Figure 54 depicts a scenario of the Internet-based collaborative environments for production layout planning.

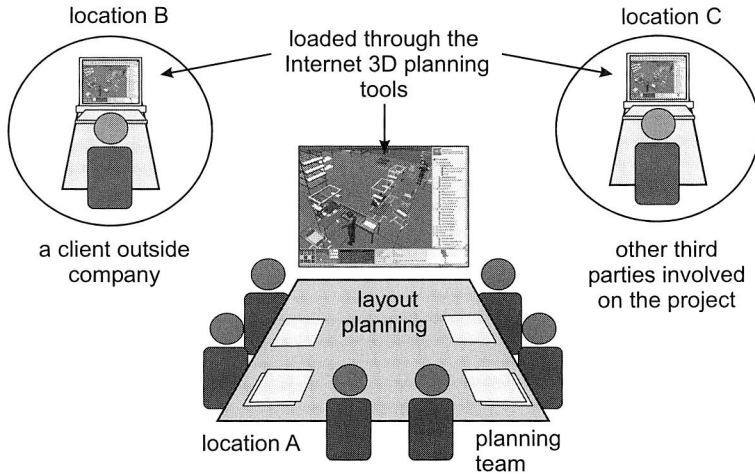


Figure 54: A collaboration scenario for production layout planning

5.3.2 Collaborative Environments and VRML

A possible solution for a standardised virtual model is the development of VRML, the Virtual Reality Modeling Language. While HTML is the current standard for authoring Web pages, VRML supports the distribution of three-dimensional models over the Internet. These models have all the characteristics of virtual models. They are based on a polygonal representation and can be animated, can include functionality and dynamic behaviour and also be able to be controlled interactively by the user.

A VRML model is defined in one or more VRML files. A VRML file is a regular text file that describes a virtual model using a standardised syntax. The content of a VRML file is being viewed interactively through the use of a VRML plug-in available for all common Web browsers (like Netscape or Internet Explorer). This plug-in can be downloaded from various Web sites which are usually available for free for different computer platforms.

When accessing a VRML file on the Web, the file is downloaded on the user's computer and the plug-in is activated and displays an initial view of the virtual model on the computer's monitor. The plug-in provides standard navigational tools like walk-through or fly-over. These tools enable the user to move through the model in an arbitrary way or along a predefined path. Navigations as well as interactions are usually controlled via the mouse input device.

Using VRML on the Web provides an excellent tool for sharing virtual models with remote users and for supporting collaborative work and concurrent engineering. It is extremely cost effective since the required infrastructure (networked computers) exists

almost everywhere and the viewing software (VRML plug-in) is available for everyone. Viewing a VRML model over the Web on a monitor provides only a non-immersive virtual reality experience. However, the syntax, data structures, and features of the Virtual Reality Modeling Language are powerful and comprehensive modelling tools that allow the description of a complete and often sophisticated virtual reality application. The application in the collaborative environments allows a group of participants located on different machines and places to interact with a single development tool as a group.

5.4 Web-based 3D Technologies

The 3D graphics on the Web or simple “Web3D” is a general term used to encompass all specific technologies for displaying and exploring Web contents in three dimensions [156]. Web3D, a relatively new term introduced by the Web3D Consortium (<http://www.web3d.org>) to describe all standard forms of the Internet 3D endorsed by that organisation, currently including VRML and X3D. These technologies, together with Java 3D and MPEG-4/BIFS, comprise the subject matter of the Web-based 3D technologies, which enable a collaborative virtual environment over the Internet. The Web3D Consortium in conjunction with other organisations are working towards Web3D technologies which are interoperable with other existing Web infrastructure technologies such as DHTML (Dynamic HTML), DOM (Document Object Model), XML (Extensible Markup Language) and others. This allows for Web3D to be at the core of Web design application and the Internet revolution.

5.4.1 Standard for Web3D Graphics

The following section presents a review of several standards for Web-based 3D graphics content in order to give a better understanding of the development of virtual collaborative environment for planning of production and assembly systems over the Internet. They include the following standards:

- VRML (Virtual Reality Modelling Language)
- X3D (Extensible 3D)
- Java 3D
- MPEG-4/BIFS (Motion Picture Expert Group/Binary Format For Scenes)
- OpenHSF (HOOPS Stream Format)

VRML (Virtual Reality Modelling Language)

The Virtual Reality Modelling Language (VRML) was developed due to an open, collaborative effort that started during the first international World Wide Web Conference in Geneva, Switzerland, in 1994. The first official version, VRML 1.0, emerged in 1995 and was based on SGI's Open Inventor technology. VRML 1.0 was limited to static 3D scenes and lacked animation and interactive capabilities. VRML 2.0 solved these prob-

lems when it was released in late 1996, serving as the basis of the ISO/IEC International Standard 14772-1:1997, more commonly known as VRML97. VRML97 made VRML 2.0 obsolete and today it is the current version of the available VRML. The VRML technology is developed and promoted by the Web3D Consortium (formerly the VRML Consortium). VRML scenes or worlds can be populated with simple or complex objects. VRML worlds and the objects they contain are defined by human-readable source code stored in plain ASCII text files that have the .wrl extension (.wrl is short for *world*). The source code contained in VRML files consists of nodes that are arranged into a scene graph data structure [34].

Scene graphs are created using nodes. Nodes are the fundamental VRML programming unit and contain data and event fields that define both, state and behaviour (VRML nodes are analogous to classes used in object-oriented languages such as C++ and Java). VRML97 has nearly 60 different built-in nodes that developers can use to construct interactive and animated 3D content. VRML nodes are used to create both, primitive and complex objects. VRML supports primitive objects such as boxes, cones, cylinders and spheres that can be used to form more complicated objects. Complex, arbitrary shapes are also supported by VRML, allowing developers to create shapes that are more natural and organic compared to those created with primitives. VRML objects are positioned in three-dimensional space according to a 3D coordinate system that has X, Y and Z axes, the unit of measurement corresponds to meters. VRML objects can have their own coordinate system or may share the same coordinate system of the scene they are in. The top-level scene coordinate system is known as the world coordinate system. By default, objects are placed at the origin of the world coordinate system. Because VRML supports any number of coordinate systems, developers use the Transform node to translate coordinate systems and also to scale, rotate and move objects.

VRML worlds can be loaded directly into a Web browser (e.g. Netscape Navigator and Internet Explorer) or into a JavaScript popup window. Alternately, VRML worlds can be woven into HTML Web pages using the EMBED and OBJECT elements (Figure 55). Introduced by Netscape, EMBED is a non-standard element that has been around longer than OBJECT and, as such, is the more popular of the two techniques. Although originally supported only by Netscape Navigator, EMBED is now supported by Internet Explorer as well. Internet Explorer also supports the OBJECT element, which was created by the World Wide Web Consortium as a standard, all-purpose object-embedding mechanism to replace EMBED and similar non-standard elements. "Sniffer" scripts can be used to determine if a user is properly equipped to view the VRML pages. Unfortunately, Internet Explorer doesn't support the same JavaScript methods as Netscape Navigator. As a result, it is necessary to use two different "sniffer" techniques to support both browsers.

The PROTO mechanism (short for prototype) in VRML97 gives developers a way to construct custom nodes that extend the base VRML language. Using the corresponding EXTENDPROTO mechanism, it can use externally defined PROTO nodes in the own

worlds. In addition, it is able to inline VRML files that contain instances of prototype nodes.

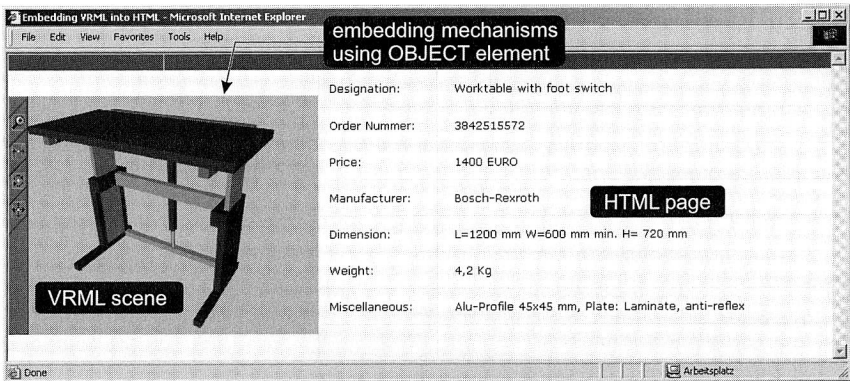


Figure 55: Embedding VRML scene into an HTML page using the OBJECT element in the Microsoft Internet Explorer

X3D (Extensible 3D)

X3D, which stands for "Extensible 3D", is a new open standard for 3D content on the Web. In essence, X3D is intended to be the new format or language that is used for 3D interactive worlds on the Web (extending the existing VRML97 standard). It will be the ISO standard for 3D graphics. This language is very robust and supports generalised 3D content for interactive Web and other broadcast media. Most important, the X3D file is encoded in Extended Mark-up Language (XML), so that it has been actually extended to make X3D more flexible than its predecessors [86].

X3D is already a draft standard and in January 2003 the X3D standard was submitted for ISO approval. At the moment only a few browsers are capable of making use of X3D files and as a result it may be a little premature to choose X3D as primary format for 3D Web content. Fortunately, VRML97 can be easily converted to X3D files, so currently it is still best to develop in VRML and convert those files to X3D as the standard becomes better if supported by browsers [107].

The examples in Listing 1 correspond to the nature of both, VRML and X3D syntaxes. Both of these examples specify a geometry box with colour appearance green, built in a shape node. These simple examples show that X3D basically keeps VRML syntaxes but puts them in the XML encoding rules.

X3D is the evolutionary successor to the ISO standard VRML97. As a result X3D has many features, when compared to VRML. These include the flexibility of X3D by using XML to provide additional data encoding functionality, new advanced rendering features e.g. multi-texturing and shadows, support of NURBS (Non-Uniform Rational B-Splines)

and Keyboard sensors. In addition, X3D can be implemented by browsers with different levels of functional ability and has a componentised architecture. Another important feature, X3D is to become the standard for 3D content in other multimedia technologies, e.g. MPEG.

VRML syntax

```
#VRML V2.0 utf8
...

Shape {
  appearance Appearance {
    material USE GREEN
  }

  geometry Box {
    size 5 4 4
  }
}
```

X3D syntax

```
<?xml version="1.0"
encoding="UTF-8" ?>
...
<Shape>
  <appearance>
    <Appearance>
      <material>
        <Material
          USE='GREEN'/>
        </material>
      </Appearance>
    </appearance>
  <geometry>
    <Box size='5 4 4'/>
  </geometry>
</Shape>
```

Listing 1: The VRML and X3D syntax differences

Java3D

Java3D is a standard Java 2 platform extension that allows developers to construct comprehensive, platform-independent applets and applications. Featuring interactive 3D graphics, behaviours and spatialised sound capabilities, Java3D can be integrated with standard Java programs and vice versa. As a layered API, the high-level Java3D API sits on a top low-level 3D graphics APIs such as OpenGL and Direct3D. Like VRML, Java 3D is based on a scene graph programming model. Developers use Java3D classes to construct scene graphs in terms of nodes, which ultimately define a virtual universe (the equivalent of a VRML world). However, unlike VRML, Java3D is tied to the object-oriented language Java. Because Java3D is based on Java, developers can exert a great deal of programmatic control over the virtual worlds they construct. Although Java3D was designed as a collaborative effort by Sun Microsystems, SGI, Intel and Apple Computer, it is not yet an international standard like VRML and MPEG-4. The ECMA standards body has recently rejected the base Java technology on which Java3D is built. Should ECMA reverse its decision and approve Java as a standard, Java3D itself will move one step closer to standardisation as a 3D graphics API.

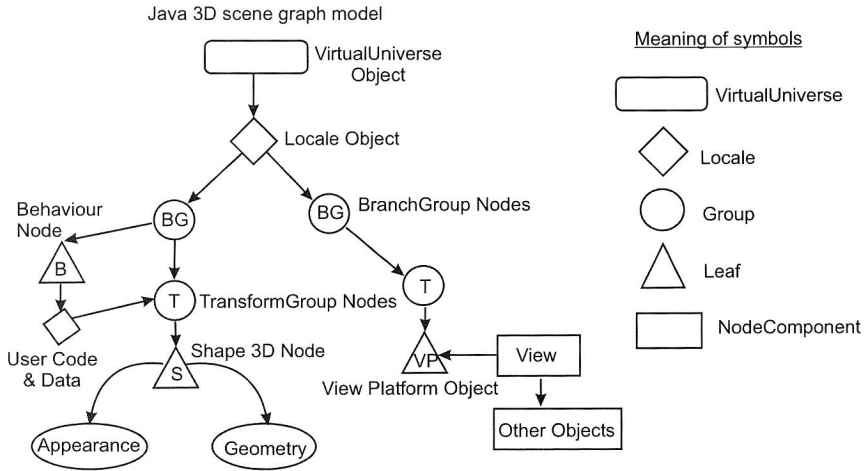


Figure 56: A Java3D API scene graph model

Like VRML, Java3D scene graphs are treelike data structures that contain node objects arranged in directed, parent-to-child relationships. Nodes, in turn, contain fields that the programmer can manipulate in order to alter their properties. Java3D scene graphs are assembled primarily from object instances created using Java3D API classes, although references to other Java objects are also legal. Most of the nodes found in a typical scene graph are descendants of the abstract *SceneGraphObject* class, which is the parent of Java3D's *Node* and *NodeComponent* classes. Nodes can be categorised as either Group nodes or Leaf nodes. A Group node can contain children, while a Leaf node cannot. Node components can be thought of as bundles of information that are referenced by nodes. A *Shape3D* node, for example, can reference *Appearance* and *Geometry* node components. Because node components encapsulate data used by a node, they are external to the node (and can therefore be shared by nodes if needed). The *BranchGroup* node is a grouping node that is used to construct and manage major branches of a Java 3D scene graph. *BranchGroup* acts as the root of a branch graph and can be selectively attached and detached from the scene graph. *BranchGroups* are typically attached to a *Locale*, which acts as a coordinate-system anchor for objects in a scene branch graph. A *Locale*, in turn, is attached to a *VirtualUniverse* object, which is the top-level object in every Java3D scene graph. The *VirtualUniverse* is the largest single unit of aggregate measurement in Java3D and can be thought of as a database in which a large number of scene graphs can be stored. Figure 56 depicts a Java3D API scene graph model [13], [156].

MPEG-4/BIFS

The Moving Picture Experts Group (MPEG) is a working group of the ISO/IEC international standards community in charge with the development of international standards

for compression, decompression, processing, and coded representation of moving pictures (video), audio and the combination of both audio and video. MPEG-4 (ISO/IEC 14496) is a toolkit of technologies specifically created to enable multimedia over slow and variable-bit rate networks (such as wireless communications devices and the Internet). MPEG-4 supports coded representation of natural and synthetic (computer-generated) audio and visual objects. MPEG-4 provides the necessary facilities for specifying how such objects can be composed together in a terminal to form complete scenes, how a user can interact with the content, as well as how the streams should be multiplexed for transmission or storage.

MPEG-4 scenes are encoded according to the Binary Format for Scenes (BIFS). As an extension of the VRML specification in a binary form, BIFS supports all VRML97 nodes in the second version of the MPEG-4 standard. In addition, BIFS introduces a number of new nodes and capabilities not found in VRML, including support for 2D shapes, 2D/3D composition, streaming, facial and body animation. As a binary format that utilises quantisation compression, BIFS content is encoded in an extremely compact and efficient manner (BIFS files are typically 10 to 15 times smaller than corresponding VRML files). To build interactive applications, BIFS defines commands that can modify, delete, or replace objects in the scene. The BIFS-Command protocol is used to send commands acting on a scene from a server to a client terminal in which the scene resides.

BIFS-Anim is a streaming protocol used to control MPEG-4/BIFS scene animation. It can be thought of as a mechanism for dynamically altering node field values over a network connection. BIFS-Anim behaves like a video or audio streaming protocol, in which a header is first sent to configure the BIFS-Anim decoder, after which frames are sent at a specified frame rate (frames contain values for fields that have been declared animated in the mask and that are animated in these frames). Although they appear to be separate protocols, both BIFS-Anim and BIFS-Command utilise the same BIFS decoder. The BIFS files can be converted from the existing VRML files. Adding commands in order to create BIFS-Command files can customise the VRML files. Furthermore, extracted animation data can be used to generate BIFS-Anim files [37], [65].

OpenHSF

The OpenHSF Initiative is an industry-wide effort to establish the HOOPS Stream Format (HSF) as a common, open and rich streaming format for sharing of visualisation data between disparate engineering applications. OpenHSF represents the truly open visualisation format geared specifically toward engineering, making it the ideal solution for sharing visual models between the myriad of applications used within the greater PLM (Product Lifecycle Management) marketplace. Supported by dozens of software vendors and end users and already imported/exported from a wide range of popular applications, OpenHSF enables lightweight 2D/3D models to move smoothly through concept, design, analysis, manufacturing, marketing, e-commerce, maintenance and end-of-life phases that make up the full product life-cycle. The members include leading

software vendors such as Dassault Systemes, PTC, MSC.Software, SolidWorks, ANSYS, Alias, CADKEY, etc.

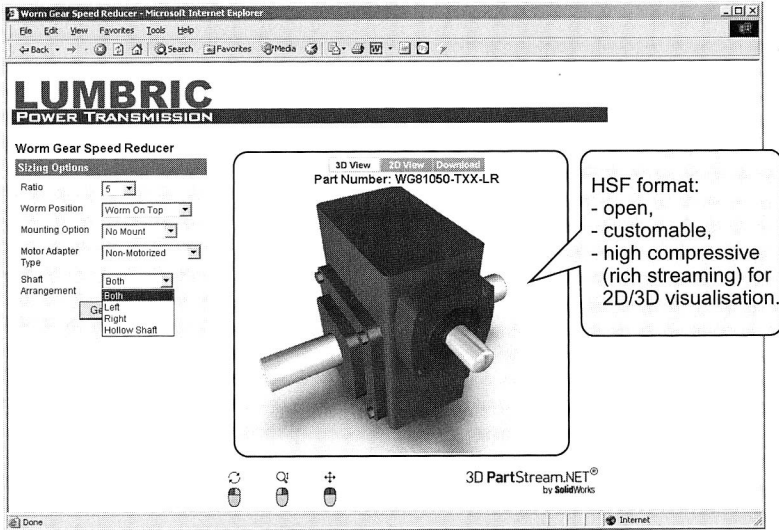


Figure 57: Online catalogue using Web3D HSF streaming file formats

The HOOPS Stream File (HSF) format is an open, customisable, highly compressed 2D/3D visualisation format specifically tailored to the needs of displaying engineering data. With the help of the OpenHSF Initiative, the HSF specification has been published and a free read and write SDK (Software Development Kit) has been made available. Using HSF, application developers can create highly customised, stream-capable visualisation files containing tessellated geometry (geometry which has a mottled appearance) as well as application-specific information (such as assembly structure, analysis data, topological data or object behaviours) and have that data intelligently associated with the tessellated model. HSF has evolved from the needs of hundreds of CAD/CAM/CAE software vendors as they sought to address the graphics needs of their end users. As a result, HSF is specifically tailored toward the needs of the engineering community and has been designed by a dedicated team of graphics technologists [116].

HSF format has been created as an open 3DWeb-streaming standard. Thus, it would be an ideal mechanism for general purpose posting of 3D models and scenes to the Web, with low cost roll out fee for the vendor or end-user. SolidWorks, as an example of member of the OpenHSF Initiative, is supporting the HSF format with their solution for online catalogue (Figure 57).

5.4.2 Barriers to Apply the Web3D Contents

Nowadays, all fundamental Web3D technologies and infrastructures have matured to a point that makes Web-based 3D content relatively easy to create, deploy and experience. Before, there was no such thing as Web3D. VRML was the only option when it came to open, standardised 3D on the Web. Unfortunately, a major technological barrier sat between VRML and the average end user, effectively walling VRML off from the general public and making it the private domain of a relatively small community of researchers, educators and 3D enthusiasts. These barriers, which can now be overcome, included the following factors:

- Internet connection speed
- Web3D platform
- Contents authoring-tool

These barriers did not disappear at all. In fact, these are issues that still exist today. These fundamental challenges originally prevented VRML from reaching masses and the next generation of VRML (such as X3D) and other Web3D technologies are being developed to overcome these challenges.

Internet Connection Speed

Web3D is delivered to end users primarily via the Internet. This means using a browser such as Internet Explorer or Netscape Navigator equipped with a plug-in. Bandwidth is always a concern when dealing with the Internet. When VRML was invented, 14.4-Kbps modems were considered fast lightning. Anyway, 3D content could take several minutes to transmit over dial-up modems with that speed.

Nowadays, bandwidth is becoming less and less of an issue. Dial-up analogue modems provide the Internet connection speed up to 56-Kbps. In addition, a variety of high speed network connections such as ISDN, DSL or cable modems are common in use and offer extremely high bandwidth that enables easy delivery of rich 3D media content [156]. In addition, the introduction of new networking technologies such as wave division multiplexing bandwidth concern will become less of a problem [148].

Beside the growth of high bandwidth modems, new technologies such as streaming, compression and Universal Media allow media-rich Web3D to be delivered over slow network connection. Streaming allows content to be delivered over the network incrementally. Compression (particularly binary compression e.g. MPEG-4/BIFS) enables Web3D scenes to be substantially reduced in size and saving precious bandwidth that would otherwise be consumed in process.

Web3D Platform

Web3D platform means the combination of substantial hardware and software, which requires partaking of immersive 3D content delivered over the Web. VRML or other

forms of Web3D are not native to the Web. A browser plug-in is required to actually handle such content and 3D environment demanded such high-powered workstations with which the user could interact. As a result, only a small segment of the Internet community has an adequate Web3D platform.

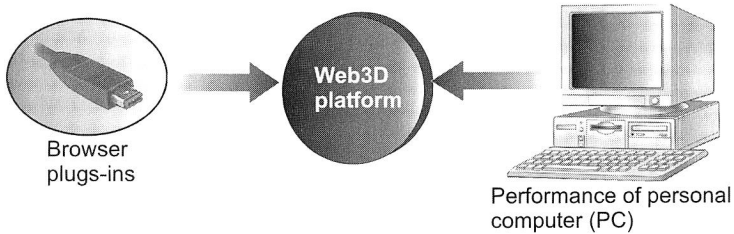


Figure 58: Improvement in personal computing power and freely available browser utilities have been emerged the Web3D platform

Nowadays, a Web3D platform has emerged for the average consumer. A personal computer now available for about €1000 can outperform high-end workstations that cost about 10 times as much only a few years ago [156]. It is reported that maximum processor speed will be reached 12 GHz by 2005 [145]. This fact also follows from Moore's Law [93], which helps to explain why computers roughly double in power and capacity every 18 months without a correspondence between rise and price. In addition, the graphic card with high-performance 3D rendering engine as well as the software side of the Web3D platform advances at an even more astonishing pace. Browser plug-ins required to handle VRML content have improved more dramatically. Today, several browser plug-ins for VRML, X3D and Java3D are already available on the Web for free. Without a doubt, a Web3D platform for the masses has arrived (Figure 58).

Content Authoring-Tool

On the one hand, the creation of 3D content with a language such as VRML or X3D requires experience, skill and a lot of time. On the other hand, nowadays there are visual development tools available that allow everyone to create powerful Web3D contents. To create a complex and fully interactive Web3D content today, only click using any of several visual authoring tools is needed. If cost-effective and powerful VRML authoring tools were available as well as X3D, Java3D and MPEG-4 authoring tools, they will undoubtedly emerge in a short coming years.

For instance, some of the VRML authoring tools from ParallelGraphics 3D technologies have been utilised in this work and more explanations how to apply these tools to create and develop a Web-based environment to facilitate a collaborative planning of the assembly systems will be explicated in section 7.2.

5.4.3 Web3D Applications

In the following sections, it will be explored how the standard for Web3D graphics has already affected the concept of Web content and has been applied in some fields, including advertising, e-commerce, product and data visualisation, training and education, virtual manual for enterprise and other engineering activities.

Advertising

Interactive Web3D is a great way to capture people's attention. After all the ineffective banner advertisement has been basically tuned out, Web surfers tune in to the three-dimensional scenes. Product placement within a 3D environment will flow naturally and can come alive when the customer gets near the advertisement. Moreover, studies have shown that people spend about 6 times longer on a Web page when interactive 3D is involved [80].

Web3D is an interactive 3D technology and can provide solutions for a market with an increasing need to communicate. Through visual impressions, Web3D can help people to understand and educate each other across cultural barriers. This means saving time and increasing sales.

E-Commerce

In recent years, the Web has become an astonishing conduit for commerce. The Web is a communications medium, which has the ability to buy, sell and advertise goods and services to customers and consumers. Today's electronic commerce (e-commerce) and general business application account for the broad majority of Web development expenditures. In this context, virtual reality in Web3D can be used to facilitate the understanding of how the heightened sense of presence is afforded by this technology. In e-commerce, this understanding can expand the range of businesses that can complete transactions in the virtual world.

More concisely, to sell online products such as mechanical devices, automobile and other equipments, the online shopper needs to experience. This fact is more difficult rather than selling online books, software or music CDs. The samples of their content can be delivered to the potential buyer digitally for a test. Web3D technologies have the potential to bridge the gap in the customer's experience, to make more products suitable for online commerce.

Web3D applications in e-commerce include product demonstrations, comparisons and configuration tasks. The application in this field will build customer confidence in knowing how the product works. The customer can go to the Web to see how to operate a product, leading more information for the buyer. Furthermore, a more satisfied customer calls the customer support centre less often [36].

Product and Data Visualisation

Without Web3D, product and information on the Web are typically presented to the viewer in the form of 2D images, descriptive text or a combination of both. Whereas, images and text are static and can only be experienced from a single perspective. Web3D allows the visualisation of the product from whatever angle the end user desires.

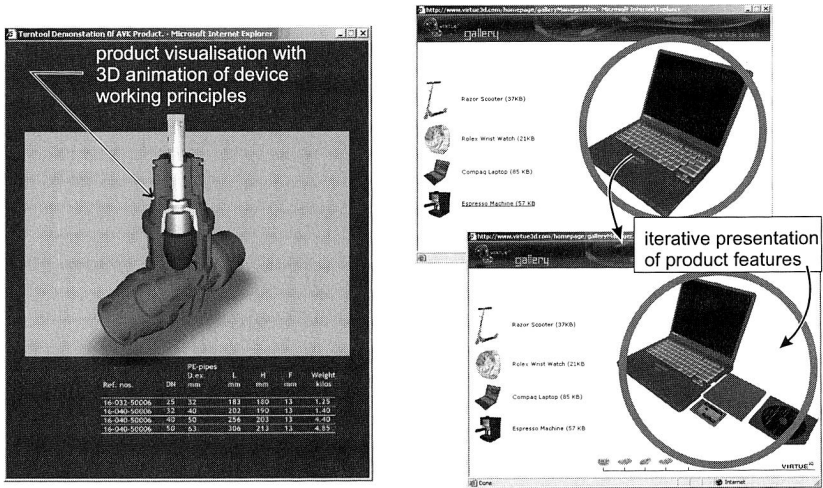


Figure 59: 3D product visualisation

With the interactive 3D product visualisation, visitors of a Web site in Internet can now experience an actual, fully functional product (Figure 59). Everybody can test and evaluate a product before buying it.

Large volumes of data sets are difficult to make sense without data visualisation, yet they can be easily understood when viewed as Web3D contents. Figure 60, for example, displays an anthropometric data set according to DIN 33402 for several percentiles (female/male) and a three-dimensional visualisation of those data sets. The 3D human anthropometric data, which describe the human body in virtual form, help to make complete information sets into an understandable form, rather than to present them in a raw form.

Learning, Education and Training

Another field of Web3D application is building interactive 3D virtual environments over the Internet as educational and training platforms. Simulations allow designers to create extremely realistic virtual spaces where students can have experiences otherwise difficult or impossible for practical, financial or safety reasons. Effective and widely available

approaches to learning, education and training can be proposed by combining 3D interactive environments, Web technologies, innovative user interfaces and pedagogical strategies.

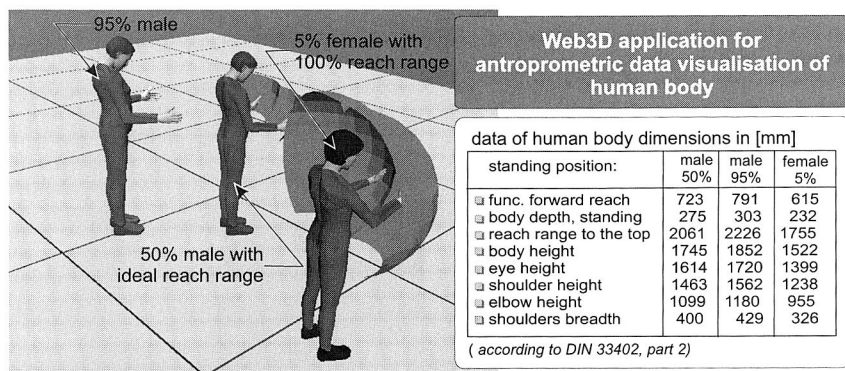


Figure 60: Web3D application for anthropometric data visualisation of human body

The Web3D applications for learning, education and training include all the issues such as interfaces, tools, technique, modelling, assessment and implementation of learning in 3D virtual environments. All the issues involved in building such as virtual learning environments for education and training uses are being explored at the moment by many researchers e.g. [20], [24], [166]. Tele-operation of robotic system is also another interesting application of this technology for training purposes [4].

Virtual Manuals for Enterprise

The virtual manuals technology is an open standard solution that enables manufacturing companies to combine their existing 3D CAD/CAE (Computer Aided Design/Computer Aided Engineering) and PDM (Product Data Management) data with their operating and procedural manuals to automatically generate Web deliverable interactive 3D simulations. Virtual manuals with 3D simulation capabilities allow complex procedures to be explained in a more intuitive and visually descriptive way than that provided by traditional product support materials. They can be delivered worldwide via Internet and viewed on standard, Tablet and Pocket PC. The application of the virtual manuals in wide range of business functions includes product maintenance and servicing, online training as well as online part catalogue.

Repurposing 3D CAD data in virtual manual technology creates significant value for both the manufacturer and its customers. The manufacturer can reuse content across many downstream functions and the customer receives improved support and documentation resulting in significant operating cost savings.

The capabilities of 3D simulations reduce the time it takes to build a *mental model* [33]. In this case, mental models are the images and assumptions carried in mind. The users will establish mental models of how things work or how they would behave in a particular situation.

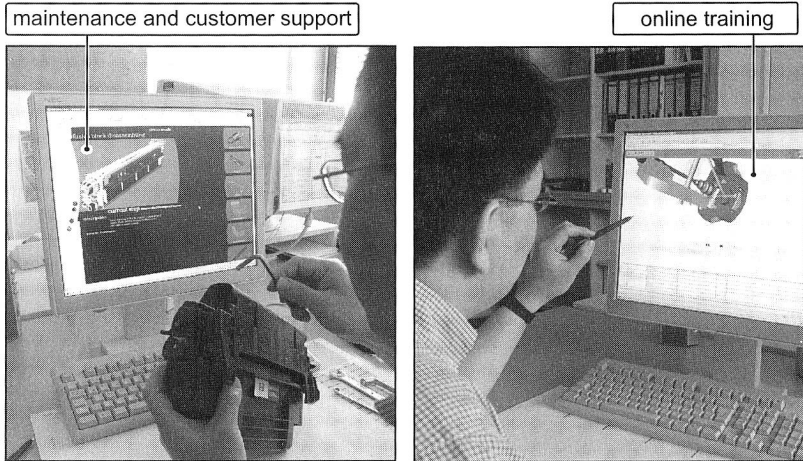


Figure 61: Virtual manual application for maintenance and customer support as well as online training

Virtual manuals for maintenance and customer (Figure 61) also support the reduction of costly mistakes. An ability to carry out complex tasks in a simulated environment prior to manipulating real equipment reduces the risk of equipment damage through incorrect actions. In addition, due to a support availability via Internet, the number and duration of support calls for service engineers will decline and the improved support documentation will increase customer self sufficiency.

3D simulations in virtual manuals provide a more life-like dynamic representation of complex technical tasks such as assembling, repair or maintenance. As a result quick user understandings have been improved. Using virtual models, the need for expensive physical mock-ups can be eliminated. Instead of travelling to take part in training, this occasion can be performed online in the workplace without travel costs. Moreover, the online nature of 3D simulations allows them to be delivered on-demand to the workplace.

Interactive 3D models of parts at the computer monitor provide a closer representation of reality than 2D isometric drawings. Thus, it improves an identification of parts. Mistakes by ordering required parts should be minimised and consequently 3D parts catalogues (Figure 62) eliminate the costs incurred through incorrect ordering of parts. Links

to the manufacturer's site can be performed directly as well as manufacturer's spare parts ordering system.

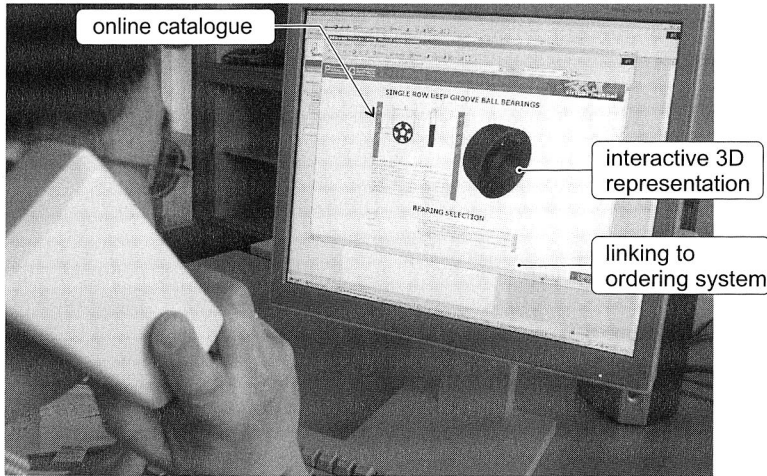


Figure 62: Virtual manual application for online spare part catalogues

Other Web3D Application in Several Fields

Currently, one of the biggest clients for interactive Web3D is the medical industry. Applications include medical procedures, such as installing new dental works, 3D visualisation of organs, new surgical devices and demonstrations of bone and muscle interactions. The medical field understands the value of 3D visualisation and is one of Web 3D's early adopters [74], [84].

Another application of 3D graphics on the Web is in the design and manufacturing. This includes the motion simulation, the virtual prototyping, the simulation of production processes and virtual factory planning [15]. In military, the Web3D application involves the visualisation for advanced graphical environment of military professional education [20]. Moreover, the application in the construction has been shown by the Research at the National Institute of Standard and Technology (NIST). It developed a mapping between product model for describing steel structures and VRML [78]. With its capability, 3D visualisation of CAD models of steel structures can be viewed in the field at a construction site.

6 Conception of Collaborative Virtual Environments for Planning of Assembly Systems in Internet

In the context of the present work, collaborative virtual environments are synthetic environments in rendered three-dimensional forms, in which users can collaborate, view and manipulate the 3D models (in this case the objects of assembly systems) along with their information. Modern Internet technologies can be applied in such environments, since they allow multiple people with simultaneous and distributed access to project data including 3D models. Collaborative and virtual environments are viewed as a reasonable way to reduce planning time and cost, improving planning quality and supporting a team-based planning process in the geographically dispersed location. It is a kind of computer-supported collaborative work system, which assists a systematic approach for assembly systems planning, and at the same time achieves a collaboration of necessary disciplines to achieve a same goal.

Chapter 6 discusses a computer-supported collaborative work and a concept of a Web-based collaborative architecture for the virtual planning of assembly systems as well as corresponding software tools for the realisation of the concept. Moreover, a prototype-planning tool, called @WebPlan, is introduced at the end of this chapter.

6.1 Computer-Supported Collaborative Work

The manufacturing planning team takes on a global character that involves distributed participants across continents. Computer-supported Collaborative Work (CSCW) systems offer solutions that could potentially enhance the productivity and effectiveness of such a team. Collaborative team-based activities change the way people collaborate and share information across the enterprise. In essence, CSCW is a set of software, hardware, language component and procedures that support a group of people in decision-related meeting. According to [92], a typical CSCW consists of five principal components, namely a database module, a model base module, a computer network module, an interface module and a facilitator. The collaborative character among project teams grows fast since the emergence and widespread use of the World Wide Web (WWW) in business, research and industrial services. It offers a tremendous potential for information sharing for people who are geographically distributed in both time and space.

6.1.1 The Characteristics of the System

The CSCW field has emerged from a growing interest on the part of the software product developers in supporting networked groups. They form a common interest among researchers in various disciplines in how the productivity of work groups can be improved. But there is another interesting fact that has shifted the research and development in the field of human-computer interaction from single user applications to group support application such as integrated product development and production planning

[3], [77]. CSCW is a mechanism that supports work activities of a group of people working on certain tasks, e.g. product development, manufacturing planning with support of the computer. For instance, brainstorming to generate ideas, structuring and then evaluating them can be facilitated by CSCW. According to [124], a CSCW system should encompass the following characteristics to ensure success:

- Interaction in synchronous and asynchronous manner among team members
- Coordination of the various tasks performed by members of the team
- Distribution in order for people to interact from remote places
- Visualisation and accessibility of data by team members
- Data hiding, that is, separating public and private data
- Sharing of data, engineering mode, application, etc. among participants

6.1.2 Groupware for CSCW Applications

Groupware is multi-user software that supports collaborative work and that addresses a variety of computer-support collaborative applications through digital media in order to bring significant improvement and transformation to organisations. Groupware builds upon the latest advance in information technology, utilising and building upon local and wide area networking, the World Wide Web, and recent advances in software and hardware technologies to achieve collaborative goals. There are hundred of commercial groupware products available on the market. Most of these products can be classified into one or more of the following categories:

- Electronic mail and newsgroups
- Group calendaring and scheduling
- Desktop video and audio and Web conferencing
- Work-flow process diagramming and analysis tools, electronic forms and routing products
- Group document handling
- Work-group utilities and groupware development tools
- Collaborative Internet-based application.

A certain type of CSCW system presented in this work focuses on the inclusion of collaborative tools to support geographically distributed work in order for assembly systems to be planned by using the Internet medium. This development is particularly significant because companies either are becoming more global in the operations or are required to collaborate with a network of global supplies and partners.

Two primary dimensions typically classify multi-user software technologies. The users are working either together at the same time (real-time or synchronous groupware) or at different times (asynchronous groupware), or they are working together in the same place (collocated or face-to-face) or in different places (non-collocated or distance).

6.1.3 Application of the CSCW Concept for Internet-based Collaborative Planning of Assembly Systems

Against the background of considerable globalisation trends, intensive partnerships and concurrent engineering in product and production developments, today's planning processes require collaborative work, information sharing and exchange of ideas among multiple parties on different locations. In a sense, manufacturing-planning systems is a distributed process that involves significant sharing of information in order to support manufacturing processes. They involve a number of engineering activities such as modelling, simulation and analysis up to visualisation through the Manufacturing Engineering Cycle. Particularly for the assembly systems, a number of applications are required to address planning tasks such as assembly process planning, time measurements, layout planning, workplace designs and ergonomic analyses.

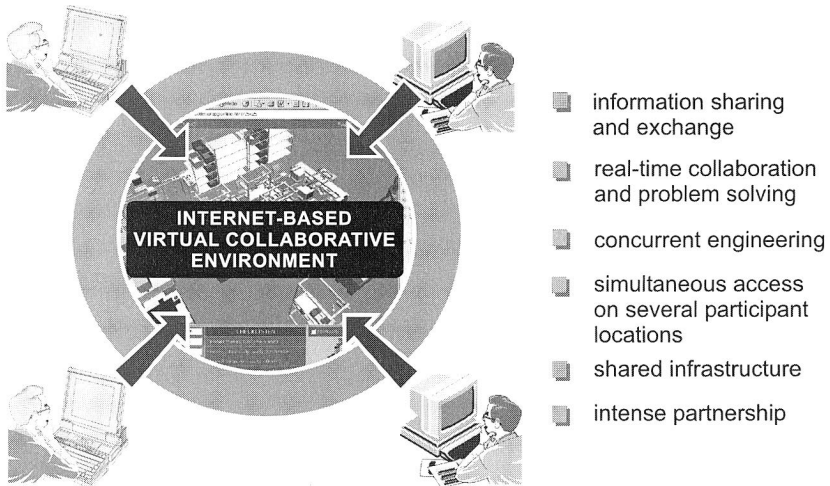


Figure 63: Internet-based collaborative virtual environments

The CSCW environment provides the demands for sharing planning data. It allows the user to access the project data including 3D layout planning of complete assembly lines and workplaces in a multiple, simultaneous and distributed manner. The challenge of a CSCW application designer is to provide suitable tools that allow participants to use, access, and organise the product or resource data in an understandable and retrievable format. The Internet and the World Wide Web (WWW) along with a three-dimensional

standard for Internet (e.g. VRML) provide 3D space, which can be used as an information sharing and communication platform for CSCW. This medium should be integrated within the planning process for assembly systems in order to result in an Internet-based virtual collaborative application (Figure 63). This Web-based CSCW application attempts to integrate main components by using a shared distributed 3D environment, namely: 1) online planning tools, 2) Web server and browser, and 3) a collaborating work group.

6.2 A Web-based Collaborative Architecture for Assembly System Planning

Compared to paper-based manual approaches, most computerised planning and design tools are stand-alone and can only provide limited support for collaborative manufacturing planning. Recent efforts have been made to convert them into Web-based systems. In contrast to stand-alone systems, even individual Web-based planning tools provide better support to collaborative production and assembly planning. They allow simultaneous access to different locations. For example, when a Web-based tool for assembly system planning is made available on the Internet, members of the planning team and other third parties can use the individual functionality of the tool to carry out specific planning tasks for the assembly lines or workplaces. The advantage of this system is the delivery of service on-demand at any time and place.

6.2.1 Planning Tasks for Assembly Systems

The planning tasks for assembly systems will be shortly discussed in this section. Each task performs a solution to support the decision process in every step of the planning phase. CAD models of the product can be used as a starting point for the planning tasks. They offer the possibility of representing the complete product structure. Further, the planning task should provide a viewing tool (product digital mock-up), which enables an efficient product design and a graphically powerful visualisation of parts, subassemblies and products. The planning task pursues systematic target costing giving a comprehensive survey of the investment cost. The processes and technology requirements to build the product and its variants according to targeted constraints and objectives will be determined on the basis of a preliminary survey. The assembly value analyses and design for assembly are subsequently further tasks for the assembly systems. They systematically detect major cost-originating parts and time supplying indicator for appropriate measures for improvement. Another planning task in the process-planning phase is cost calculation. Thus, the required time of each manual task can be estimated by using a predetermined time system. In summary, all assembly sequences and tasks will be distributed among a set of workstations (line balancing).

The next stage involves defining the assembly line layouts and the material flow model. Material flow simulations verify line performance, throughput, resource utilisation and bottleneck analysis. A detailed workstation design is developed in the following steps.

Tasks that are performed in this phase include layout of workplaces, selection, dimensioning and arrangement of operating materials, ergonomic and cost analysis. If necessary, a simulation of the worker's assembly sequences can be performed.

Figure 64 shows different planning tasks for assembly systems. The framed rectangles with black background colour comprise the planning tasks such as digital mock-up, time measurement, line layout, workplace design, and ergonomics. The present work develops the tasks mentioned to Web-based application modules for virtual collaborative planning of assembly systems.

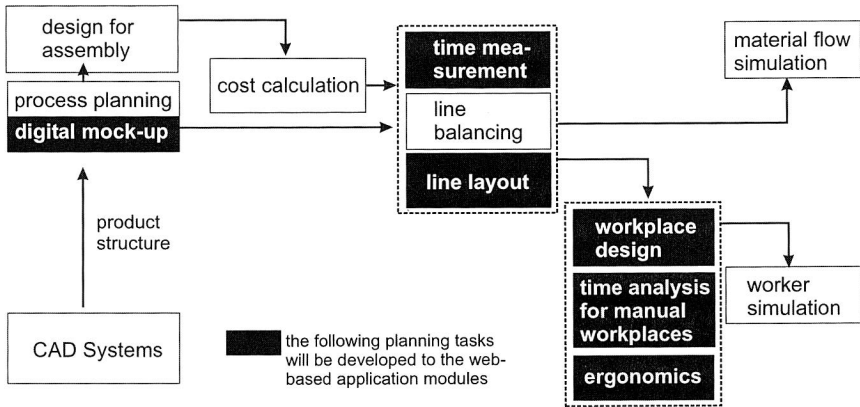


Figure 64: Planning tasks for assembly systems

6.2.2 Distributed Collaborative Virtual Planning

A distributed collaborative virtual planning of assembly systems contains two parts. One is a client-side application, which is a Web browser with an embedded virtual environment for planning purposes and the other is server-side application, which is a Web server. The client-side application performs the planning tasks for assembly systems. In this work, the planning tasks for assembly systems such as time analyses (according the MTM Method), line layout and workplace design with ergonomic considerations should be performed by the client-side applications. The server-side application takes care of communication and coordination. The server-side application also provides procedures so that data of the planning results (e.g. in XML and VRML format) can be saved or uploaded to the server as well as loaded or downloaded from the server.

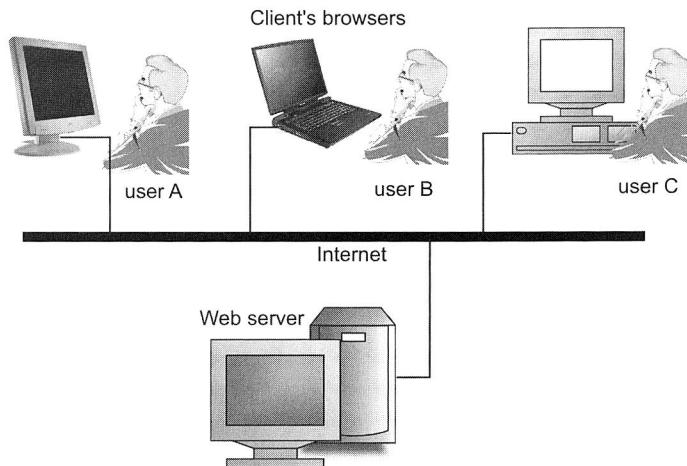


Figure 65: A distributed collaborative virtual planning

The distributed collaborative virtual planning application works as follows (Figure 65). There are three users in a planning group, who are geographically dispersed in a large network. Firstly, user A joins the planning environment by accessing the URL of the program using the Web browser (e.g. Microsoft Internet Explorer). The browser allows the user to locate a planning task such as assembly line layout, to access the required data and to interact with models on the server. Subsequently, the Web server delivers the corresponding packets to the client's browser. Using several functionalities of the planning tool such as 3D graphic tools (e.g. to assign, move, turn, or collide 3D objects) as well as the 3D models in the objects library or other 3D models from the third parties, this planning tool allows creating and visualising the 3D layout of the assembly lines. A work-in-progress can be saved on the server. Further, user A informs other planning teams (e.g. user B and user C) through a chat room, that at the moment the rough version of an assembly line layout has been located on the Web server. Using the same application, which is delivered on-demand through the Internet, the users B and C join the virtual environment and user's A temporary planning results are loaded from the server. Now, all users, who are geographically dispersed, can collaborate and view the same 3D model of a line layout.

Thus, each of the users is enabled to distribute the planning task in order to complete the model. Any changes in the assembly facilities layout can be immediately informed to the other members as well as displayed in the 3D area. The online, distributed, and collaborative virtual environment with 3D capabilities allows the parties in different locations to speed up the exchange of ideas, reduce misunderstandings by means of visualisation and improve the collaborative planning processes.

6.2.3 Web-based Client-Server Architecture

This work presents distributed collaborative virtual planning environments, which are based on Web-based client-server architecture. In this architecture, the client of the system is a Web browser (Microsoft Internet Explorer) and the Apache Web server has been implemented as server software behind the Web. Thus, multiple planning spaces can be set from a server and the planning services can be delivered on-demand to distributed participants.

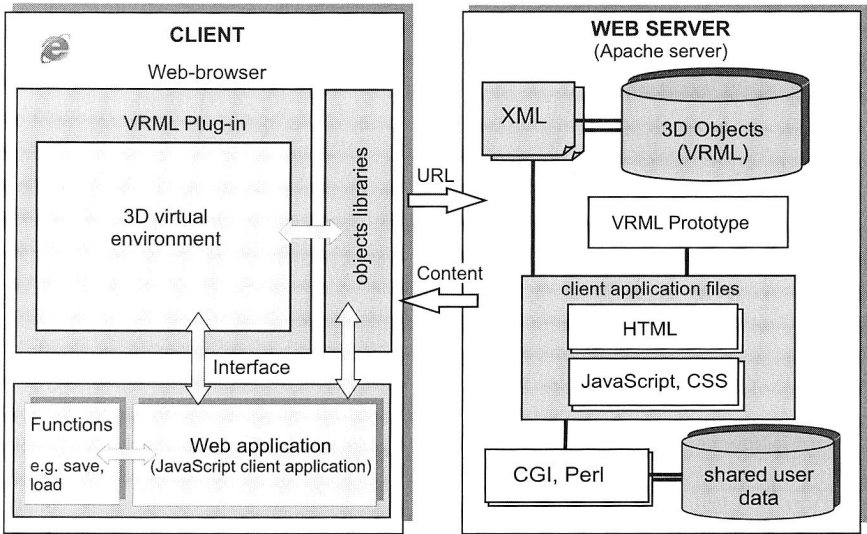


Figure 66: A Web-based client-server architecture

An overview of this architecture is shown in Figure 62. As shown in this figure, the components of this client-server architecture are presented in the form of functional blocks and their interrelations. The main aspect of the architecture structure is the static structure in terms of components, their interconnections and interfaces and operations offered by the components. These components include a Web server for storing and managing different data types. On the other side of the architecture is the client component, which is a Web browser along with the respective plug-ins for exploring 3D models from a virtual environment over the Internet. The communication between client and server is conducted by means of a Hypertext Transfer Protocol (HTTP). Thus, a request for a service is initiated by typing an Uniform Resource Locator (URL) address and the server locates the request and forwards the corresponding contents to the client.

Client

As a Web-based platform, the client of the system in this work is Microsoft Internet Explorer. This browser is utilised by the user in order to locate and display the Web pages,

which consist of 3D contents and other related functionalities for a distributed collaborative virtual planning environment. A special plug-in like Cortona VRML Client from ParallelGraphics product, which is embedded within the browser, is required for viewing 3D contents.

On the client's side, several application-programming interfaces (APIs) allow a JavaScript client application to be integrated with this 3D virtual environment. Thus, a specific application within the browser can interact with 3D contents (in this case VRML data). In addition to this client application, an object library is available for the client's engine. The library is a collection of 3D objects, which can be assigned and simulated in a 3D virtual environment.

Web server

The Web server is used to store data and serve them for clients. The data for this application include 3D contents in form of VRML objects; client-application files e.g., HTML, CSS, JavaScript files as well as XML documents for objects system library. The server contains a special VRML prototype, which provides costumed, extended VRML-nodes as the core components of this application. Moreover, the Web server stores and executes CGI Scripts written in PERL in order to perform specific functions like saving or opening the planning result to/from the server.

In this architecture, Apache Web server Version 2.0 is applied as software behind the World Wide Web. Apache is a freeware and has sparse documentation and no direct technical support. The Web server using Apache interacts with the Web browser using HTTP protocol and the other components such as objects libraries and a three-dimensional shared virtual environment in order to implement a specific functionality.

6.3 Software Tools for the Realisation of the Concept

Several software tools have been utilised for the realisation of a Web-based concept for virtual collaborative planning of assembly systems. They include:

- VRML browser,
- VRML authoring tool,
- Web server program,
- Software Development Kit (SDK) for development of 3D enabled applications,
- Client-side Web programming.

6.3.1 VRML Browser

The most common way to view VRML files (.wrl extension) is a VRML browser, also known as a plug-in, client, player, viewer, toolkit, program, or ActiveX control. VRML browsers or plug-ins can be downloaded and installed on the computer or on the Web

browser. Some of the VRML browsers can also display X3D files. They are intended to work in conjunction with Web browsers such as Microsoft Internet Explorer or Netscape, providing a navigational tool into virtual 3D worlds. These worlds can contain 3D objects, which represent several production facilities for the layout-planning problem. The following table presents some commercial software for viewing VRML files and their features.

Software	Type	Operating System			Web browser		X3D
		Window	Linux	Mac	IE	Non-IE	
Cosmos Player	Plug-in	✓			✓	✓	
Cortona	Plug-in	✓		✓	✓	✓	
BS Contact	Plug-in	✓			✓	✓	✓
Vcom3D	Plug-in	✓			✓		✓
Octaga	Plug-in	✓			✓		✓
Flux	Plug-in	✓			✓		✓
FreeWRL	Plug-in, program		✓	✓		✓	✓
BS Contact J	Applet	✓	✓	✓	✓	✓	
Blaxxun3D	Applet	✓	✓	✓	✓	✓	
Dynamic-3D	Applet	✓	✓	✓	✓	✓	
FastScript3D	Applet	✓	✓	✓	✓	✓	
Xj3D	Program, toolkit	✓	✓	✓			✓
VRML View	Program	✓	✓				

Table 3: VRML browsers and their features

Cortona VRML Client

A VRML browser called Cortona VRML Client from ParallelGraphics has been used in this work to view 3D scenes on Web pages. This browser functions as a plug-in on client machines. Cortona VRML Client is a fast and highly interactive Web3D viewer that is ideal for viewing 3D models on the Web. A set of optimised 3D renderers guarantees the best visual quality on both PCs with the latest video-cards and those with more basic video card capabilities. This viewer works as a VRML plug-in for popular Internet browsers such as Internet Explorer, Netscape Navigator, Mozilla and Opera as well as office applications such as Microsoft PowerPoint and Microsoft Word. However, Cortona

Client is more than just a plug-in. The powerful Automation Interface allows adding exciting 3D capabilities to the Web site and to the standalone applications.

The Cortona VRML Client has the following features:

- Complete VRML 97 support, including Java and JavaScript support
- Support of modern 3D accelerators via DirectX and OpenGL
- Advanced rendering: mipmapping, phong lighting, reflection mapping and enhanced anti-aliasing
- Optimised for Intel Pentium III and Pentium 4 processors
- Additional nodes and capabilities extending the VRML specification
- Support for Macromedia Flash and skins with JavaScript support
- VRML Automation Interface based on the ActiveX Automation technology
- External Authoring Interface (EAI) and 2nd EAI for Internet Explorer support

6.3.2 VRML Authoring Tool

The VRML authoring tools are likely to become the backbone for all Web3D content development effort. The tools allow us to model geometric visually while the VRML code is written automatically in the background. Behaviours and animation features can be added to the objects to give them the interactive and dynamic 3D models. Other authoring tools enable to program and develop a professional VRML content, e.g. new prototype. According to their functionality, they can be categorised as follows:

- an editor tool for VRML programming,
- a tool that facilitates the creation of interactive and dynamic 3D scenes,
- tool for creating 3D models for the Web,
- a tool for optimising complex 3D models, which originate from CAD systems.

In this work, there have been used several VRML authoring tools from ParallelGraphics products. They include VRMLPad, Internet Scene Assembler, Internet Space Builder (ISB) and Internet Model Optimizer (IMO). These products are discussed below.

Internet Space Builder (ISB)

Internet Space Builder (ISB) from ParallelGraphics is a user-friendly authoring tool suitable for designers of all levels. With ISB, creating 3D models for the Web is now easier than ever. It adds a new dimension of reality to the Web sites with a complete library of

editable 3D shapes. Combined with interactive texture mapping ISB brings the 3D space to life.

Although this software offers many considerable advantages of creating 3D models for the Web, most of the 3D models created in this work have been converted from 3D models originating from CAD/CAE systems, e.g. AutoCAD, ProEngineer, Ergomas.

Internet Model Optimizer (IMO)

IMO is a VRML-tool, which provides an efficient way to optimise complex 3D models originating from CAD/CAE systems and other sources for use on the Internet. In many cases, the number of primitives in these models overwhelms the rendering performance of current graphics systems.

One method for accelerating the rendering of these environments is polygonal simplification. The aim of polygonal simplification is to remove primitives from an original mesh in order to produce simpler models that retain the important visual characteristics of the original object. The optimising technique uses a successive vertex removal technique with the corresponding triangulation to gradually simplify a model. This method is relatively fast and allows us to simplify large polygonal models with hundreds or thousand of polygons in several minutes by using ordinary PCs.

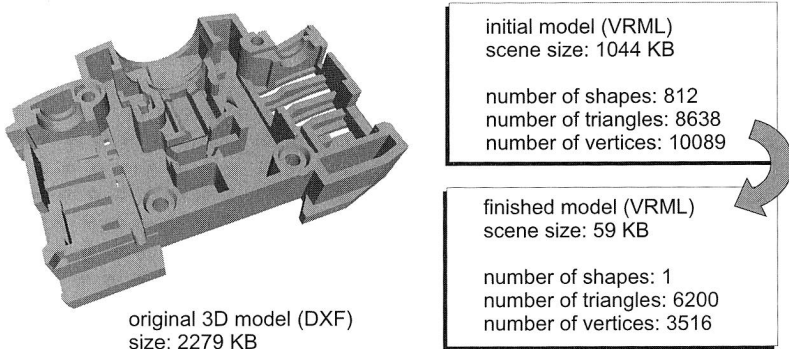


Figure 67: Optimisation of complex 3D models originating from CAD/CAM/CAE systems using Internet Model Optimizer (IMO)

Internet Model Optimizer offers a wide range of optimisation modes, from batch processing to manual mode with the ability to optimise only the selected parts of the model. Figure 67 shows an optimisation result for a 3D model of fuse housing, which utilises these software tools. A 3D model of a product originating from CAD systems (in this case from AutoCAD/ DXF format) has been primarily exported into a VRML format. The initial model (VRML) with a size of 1044 KB has been reduced into a 3D VRML model with a size of 59 KB. This means that the finished model has a 17,7 times smaller size than the initial one.

Internet Scene Assembler (ISA)

This kind of VRML authoring tool facilitates the creation of interactive and dynamic 3D scenes for the Web. ISA's user-friendly interface means that both experienced Web designers and relative novices can create exciting 3D environments. Internet Scene Assembler (ISA) features include its ability to create intelligent objects with animation, with interactivity and complex behaviour, to assemble 3D scenes with intelligent objects, and to create guided tours through 3D scenes. Figure 68 shows how to apply this software tool in order to create a virtual interactive industrial robot with animated joints as if they were real ones. Each object in the scene can be endowed with a wide range of abilities (such as movable, turnable, etc.), which allows creating complex object behaviour. In addition, the visual routing diagram specifies how the objects should react to the events in the scene and to the user's actions.

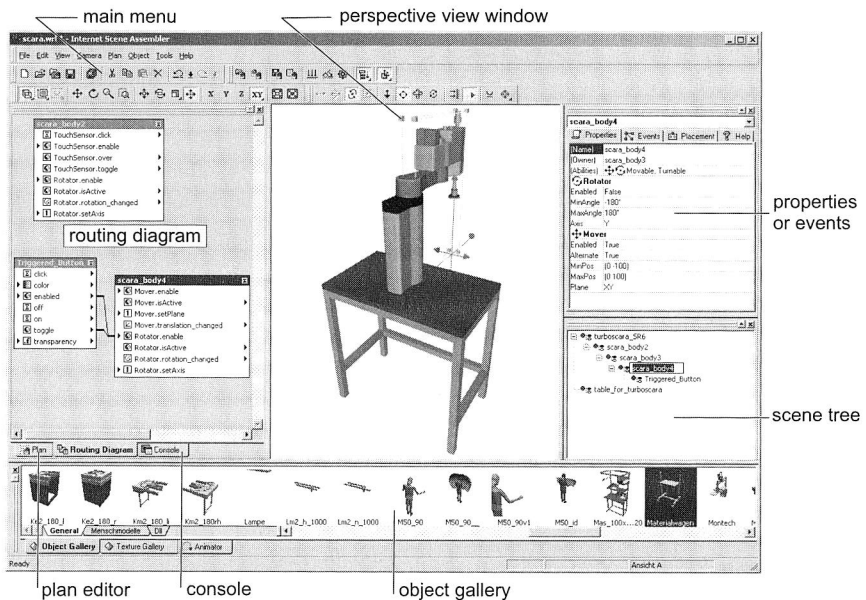


Figure 68: Internet Scene Assembler to assemble pre-made objects into interactive, dynamic 3D models

VrmlPad

VrmlPad is a powerful and flexible authoring tool from ParallelGraphics that allows designing and developing professional VRML content. It creates VRML worlds that are published on the World Wide Web and it fully supports the VRML 97 specification.

VrmlPad features include text editing to access local and remote files as well as document tabs to open and edit multiple documents, finding and replacing all opened documents as well as file dependencies of the active document. This editor can dynamically detect semantic errors or warnings of undefined identifiers as well as non-matched fields, and more. It provides a scene tree to view, edit and navigate hierarchical scene structure. The scene can be previewed in installed browsers and VRML viewers. One important feature is automation and scripting in order to manipulate the program from external applications by using the C, C++, Visual Basic®, or HTML application. In addition, advanced users can create add-ins, VBScript and JavaScript macros and execute them within the VrmlPad environment in order to automate custom tasks and add visual support.

6.3.3 Web server

A Web server is the server software behind the World Wide Web. It grants a client's request in the same way a browser (Netscape or Microsoft's Internet Explorer) does. When it gets one, it processes that request and returns certain data. This data usually takes the form of a formatted page with text, graphics and even 3D contents. The browser then renders this data to the best of its ability and presents it to the user. Web servers are conceptually very simple programs. They wait for requests and fulfil them when received. There are many Web server software applications, including public domain software from NCSA and Apache, and commercial packages from Microsoft, Netscape and others. In this work, the Apache HTTP Server Version 2.0 has been implemented as a powerful and flexible HTTP/1.1 compliant Web server.

The Web server communicates with browsers or other clients by using the Hypertext Transfer Protocol (HTTP), which is a simple protocol that standardises the way requests, are sent and processed. This allows a variety of clients to communicate with any vendor's server without any compatibility problems. Most of the documents requested are formatted with the help of Hypertext Markup Language (HTML).

Server-side Programming

Server-side programming describes any code, software or script that is executed by the Web server. Since these applications reside on the server they can interface with other server-side resources such as databases. Generally, server-side programming has two programming types namely server-side scripts and server pages.

In this work, CGI (Common Gateway Interface) scripts written in PERL (Practical Extraction Report Language) have been applied in order to interact with the Web environment (e.g. for processing data sent by a browser). The CGI is a kind of server-side scripting (small program) that resides on the Web server and interacts with the Web environment. When browsers execute scripts that are linked to the code file, the script will function as designed (e.g. saves the planning data) and return a dynamically generated page.

6.3.4 Software Development Kit (SDK)

Software Development Kit (SDK) facilitates a quick development of 3D enabled applications. It provides an application programming interface (API) that enables authors and developers to integrate a Web3D technology into other applications by using Visual C++, Visual Basic, Delphi, and third party applications supporting ActiveX technology (like MS Access, MS PowerPoint) as well as HTML and Java applications. In this work, the 3D models have been integrated into collaborative environment by using Parallel-Graphics Cortona® Software Development Kit, which allow the planner to manipulate 3D models from a Web application, based on the Cortona VRML client. As a result any changes in the assembly processes and production facilities layout are immediately displayed on the 3D area.

6.3.5 Client-side Programming

In computer networking, the term client-side refers to operations that are performed by the client in a client-server relationship. In this context, the client makes a request and sends it to the Web servers. The server handles the request and responds. The client downloads programs, which are associated with Web pages on the server. These programs are then executed locally on the client's computer by a Web browser. Depending on the kind of programs or script languages, they require proper plug-ins on the client's machine to run properly. Clients with older browsers, or non-standard settings, may experience problems. In order to develop such a Web-based virtual collaborative system for the planning of assembly systems, a client-side Web programming is required. This includes several client-side programming languages using HTML, CSS, XML, DOM, JavaScript and Microsoft Internet Explorer's Dynamic HTML capabilities, which have been briefly described in section 5.2.

6.4 @WebPlan - a Web-based Application for Planning and Design of Assembly Systems

A Web-based application for the planning and design of assembly systems, called @WebPlan, has been developed in the present work by using client-server architecture (Figure 69). The planning tool is accessible over the Internet and can be connected through several client users in order to facilitate a virtual collaborative work among geographically distributed teams. In addition to the Internet implementation, this planning tool can also be used either on the Intranet within limited area or as single application on a local PC.

@WebPlan is a flexible 3D planning and design service for assembly systems on the Internet that enables groups of users to collaborate and present such a complete assembly line or an improved workplace to other clients over the Internet or the company Intranets. The three-dimensional virtual environments within the application allow users by mouse clicks to create and simulate their virtual model of assembly facilities layout. This planning process will be enhanced by using comprehensive objects libraries, which

are incorporated in the planning environment either as internal objects libraries (available on the server) or as external objects libraries (downloaded from other servers). Several functionalities for certain tasks have been deployed in order to deal with the planning requirements.

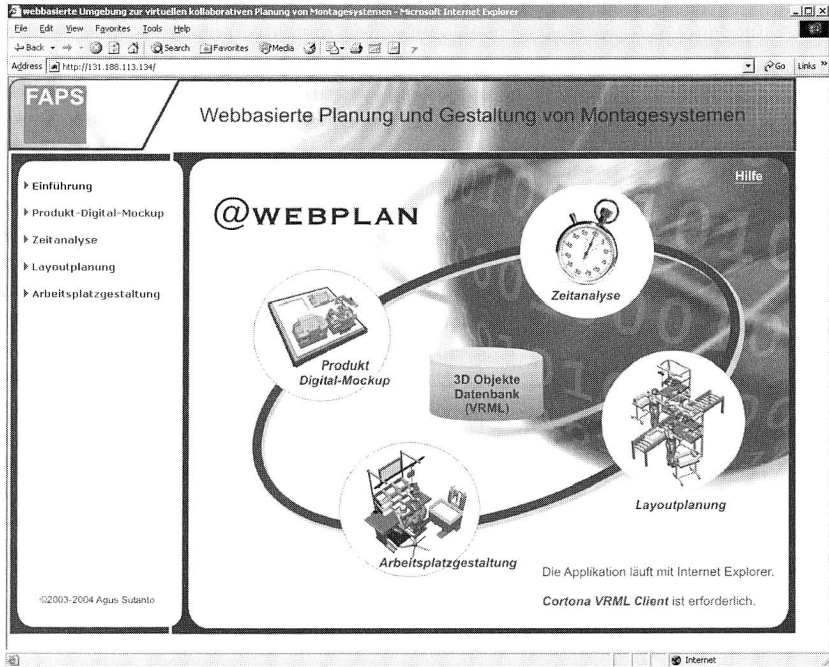


Figure 69: @WebPlan, a Web-based application for planning and design of assembly systems

The Web-based application is equipped with a data management, which allows the client's user to save, load, upload and download the planning result to/from server on the basis of VRML and XML files format. The @WebPlan planning tool allows the parties in different locations to speed up the exchange of ideas, reduce misunderstanding, to plan concurrently and facilitate problem solving and as a result significantly improve the collaborative planning and design process.

The present work has developed several Web-based application modules in order to meet collaborative virtual planning requirements for assembly systems. The following are the existing modules for a Web-based collaborative virtual environment.

- **Digital Mock-up:** supports product digital mock-up
- **Layout planning module:** responsible for designing the layout of assembly lines

- **Workplace layout design:** a system for workplace layout design with ergonomic considerations
- **Time analysis module:** provides time estimation and the analysis of working sequences according to the MTM-Method.

Figure 70 depicts the Web page screen shoots of each module, through which the corresponding developed Web-based applications can be joined and run.

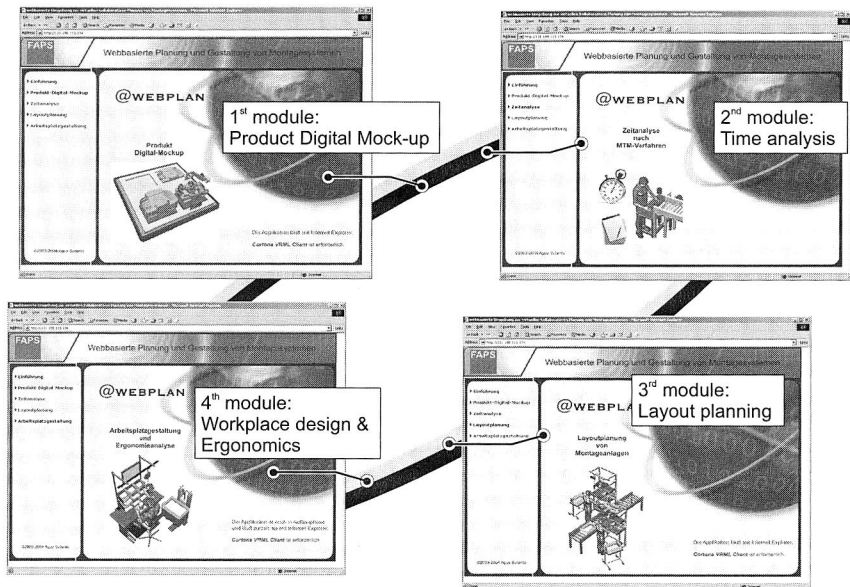


Figure 70: The modules of the developed application

A Web-based module for digital mock-up serves in this section as an exemplary for the Web-based collaborative virtual environments, which is currently being developed (Figure 71). Here, the term digital mock-up (DMU) is a collection of 3D models, which are positioned in a 3D space to represent the form of the product to be developed [11], [123]. This application allows full visualisation of complete products in three dimensions. A Web-based digital mock-up can be seen as an additional alternative to a digital product development, which permits collaborative engineering among users. This module can be used as a starting point for further planning tasks. It provides a viewing tool, which enables a graphically powerful visualisation of parts, subassemblies, and products. Product design information, which is available in this module, pursues the systematic planning process, particularly for layout structure or at workstation level.

The system enables the access to all geometry via mock-up database by means of an online product library. Each 3D model (in VRML format) is attached to a part in the product structure. In addition to the 3D model on the server, external parts or sub-assemblies from other partners (e.g. customers or suppliers) outside the server can be accessed by the system. Then, they are stored in a tree-like diagram in the system's navigation panel for design purposes.

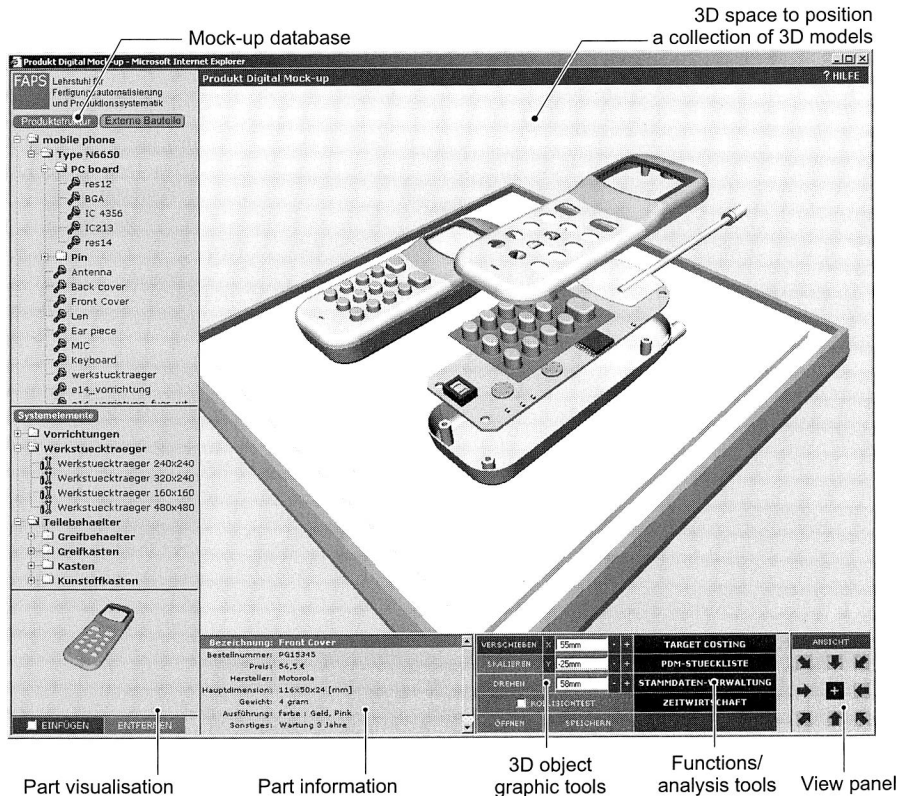


Figure 71: A Web-based prototype module for digital mock-up

The application provides a 3D space in order to position a collection of 3D models to create the mock-up. Each of the selected parts in the database will be visualised separately and the corresponding part information will be presented in a certain panel. In order to digitally simulate the product in the virtual environments, a collection of 3D graphic tools is available. The tools enable each of the 3D objects to move, turn or scale in a global coordinate system. Furthermore, using the developed system the collision test between several parts in the virtual environments can be carried out. Thus, the product digital mock-up result can be saved in a client-server framework. The result

data saved on the server can also be loaded and then revised by other parties. This online environment with 3D capabilities allows parties in different locations to speed up the product development. The planning and design of the assembly systems can be performed based on the product data. Oppositely, the planning problems can already be considered from the assembly point of view in the design phase.

The other remaining modules such as the layout-planning module that is responsible for designing the layout of assembly lines will be comprehensively discussed in Chapter 7. Workplace layouts with ergonomics considerations and a time analyses module, which provides time estimation and the analysis of working sequences according to the MTM-method, will be explored in Chapter 8.

7 Development of a Web-based Prototype for Layout Planning of Assembly Lines

First, this chapter discusses the approaches and computer tools for the layout planning, which are available on today's market, as a background to develop a new Web-based prototype for layout planning of assembly lines. A design concept of the software prototype will be introduced in the next section. Subsequently, Chapter 7 addresses the realisation of a Web-based software prototype.

7.1 A Review of Computer Tools for Layout Planning

Several computer tools that address different approaches for layout planning of production systems will be reviewed in this section. They include the computer-integrated approaches with application of 3D digital models, Virtual Reality techniques and participative and team-based planning approaches. Most of them are commercially available on today's market.

There are a number of software companies, which use digital models for layout planning in their applications. They include a software module eM-Workplace NT [35] from Tecnomatix and another Process Engineer's module, called Layout Planner [99] from Delmia. EM-Workplace NT, one of eMPower software solutions, offers a computer tool for planning and designing complex assembly facilities, lines and workplaces. It incorporates both planning and engineering tools and supports a structured process from block layout, over line planning to detailed design and optimisation of individual workplaces. Layout Planner from Delmia solutions offers a similar computer tool for layout planning. This tool supports the simultaneous concept of production planning. The layout planning procedure begins with a manufacturing concept, then turns to a system layout of the work system and ends with a layout design of manual and semi-automated work places. This software tool also provides a library of 3D models with commonly used manufacturing resources in order to quickly solve problems regarding the plant layout.

The computer tools, which are based on Virtual Reality techniques, have also been released for the layout planning. Besides the classical 3D visualisations, they use the stereoscopic visualisations in order to lead an intuitive understanding of the layout problems and to allow real time interactions and to enhance the collaboration within the team. The software solution Virtual Planner from IMS GmbH is one of the computer tools mentioned above. Another computer tool, called TaraVRbuilder [101] from Tarakos GmbH, can be used to configure and generate realistic and dynamic 3D worlds for factory planning and materials flow presentations. In order to build a virtual model of production and assembly facilities, this tool has the standard library, which consists of several industry-specific components, vehicles or machines. TaraVRbuilder is based on the VRML technology and allows the 3D models of assembly plant layouts or material flow facilities to be displayed on the Internet. In addition, by using a stereoscopic projec-

tion system with 3D glasses a stereoscopic presentation of the dynamic 3D worlds can also be performed.

Another technique for layout planning is the participative and team-based approach. This approach can be found in the Planning Table system from Fraunhofer IPA, Stuttgart. This system has the objective to place creativity in the forefront, while the computer slips into the background. In order to enable the planners to envisage their facility in spatial terms, a three-dimensional picture is also projected onto the wall. As a result, this system increases planning quality and encourages communication [161].

According to the review of several computer tools, most of them offer an isolated solution without support of collaborative work, information sharing and exchange of ideas among multiple parties in the different locations. The computer tool TaraVRBuilder, for instance, enables to represent the layout result online on the Internet for users in different locations, but it cannot perform a collaborative layout planning process on the Internet. In a strict sense, a participative and team-based approach by means of the Planning Table provides collaborative work, but the interaction occurs only at the same time and in the same place. The developed Web-based prototype should possess both synchronous and asynchronous capabilities on a single platform in order to perform the layout planning process of assembly systems from the same or different location as well.

7.2 The Design Concept of the Prototype Software

The design concept of the prototype software utilises the Web and Web3D technologies. The VRML is a 3D graphics technology on the Web, which is based on the implemented software. Therefore, the interfacing process between VRML 3D Scenes and a Web Application will be discussed at the beginning of this section. The combination of substantial hardware and software platforms for the software environment will be addressed afterward. The VRML techniques and an XML based objects library for the prototype design will be considered at the end of this section.

7.2.1 Interfacing VRML 3D Scenes in a Web Application

This section discusses how an external application, in this case a Web application, interacts with 3D-rendered scenes in a Web browser. There are a number of Web3D technologies and 3D viewers available on today's market, therefore the discussion focuses only on VRML technologies from ParallelGraphics (Cortona VRML Client) as well as the application programming interface (API) technologies provided by ParallelGraphics Cortona® SDK, which has been implemented in the developed prototype.

Firstly, it will be explained how Web pages can display VRML scenes by using Cortona VRML Client. This VRML browser works as a plug-in on client machines. It has an ActiveX Control (also called Cortona Control), which is a windowed control that enables an application (Web page) to interpret files in the VRML97 file format, presents their content to the user in the window application (Internet browser) and supports the user's

interaction with the scenes. Cortona Control, which is a core element of ParallelGraphics Cortona VRML Client, can be used in any environment that supports Component Object Model (COM) and Object Linking and Embedding (OLE) technologies. This active control has a unique identifier (called CLSID) that identifies a COM class object and has the following value: {86A88967-7A20-11D2-8EDA-00600818EDB1}. This functionality and various settings of Cortona Control are provided by its properties, methods, events and related objects.

To display a VRML scene in a Web browser, authors should use the EMBED or OBJECT (supported by Microsoft Internet Explorer) element with the proper attributes in an HTML document. It is embedded into HTML by using the following tag:

```
<OBJECT ID="Scene" TYPE="application/x-oleobject"
CLASSID="CLSID:86A88967-7A20-11D2-8EDA-00600818EDB1" WIDTH="100%"
HEIGHT="100%">
<PARAM NAME="SRC" VALUE="myVrmlFile.wrl">
</OBJECT>
```

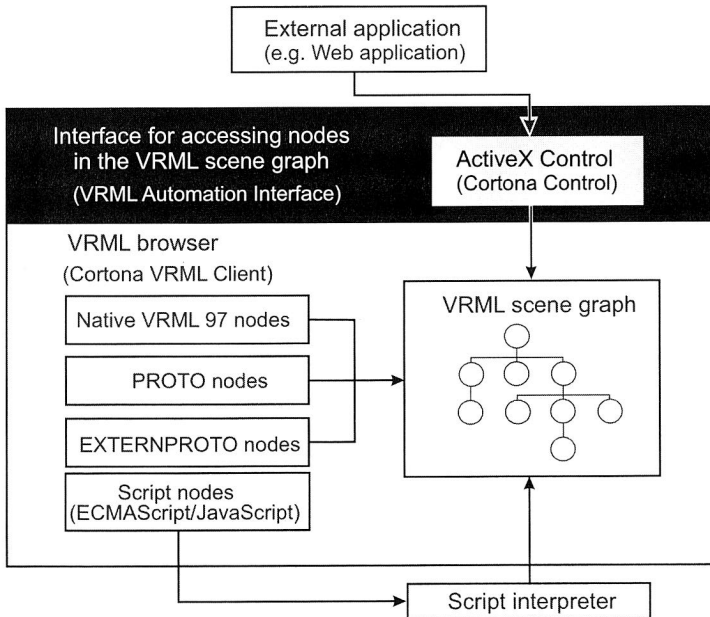


Figure 72: Interfacing a VRML scene from an external application.

In addition, this OBJECT tag also refers to Cortona Control objects written as JavaScript functions on the HTML pages. These functions enable in the run-time mode (1) to read and set new values for the properties of Cortona Control, (2) to invoke methods of Cor-

tona Control, (3) to create event handlers of Cortona Control and (4) to get access to the VRML scene graph.

Particularly for the function of getting access to the VRML scene graph, which is implemented in this prototype software, a set of interfaces called the VRML Automation has been utilised. The VRML Automation, which is a part of Cortona SDK application, defines the interfacing processes between the VRML scene and the external environment. It contains a set of interfaces, which can be used for performing operations with various components of a VRML scene like nodes, prototypes, fields, routes or values. Thus, an external application (in this case a Web application/JavaScript-enabled application on an HTML page) can affect or obtain parameters from the VRML scene. This includes the collection of 3D objects composed as a building-blocks hierarchy in the VRML scene graph.

Figure 72 depicts in form of functional blocks the interface of a VRML scene graph from an external application. A set of interfaces called the VRML Automation has been utilised to access the collections of nodes and prototypes and the collection of fields of the node in the scene graph, as well as to access the PROTO and EXTERNPROTO nodes. Furthermore, Script nodes, e.g. JavaScript, can be embedded within a VRML scene graph in order to extend its programmable behaviours.

7.2.2 Implementation Platform

In this context, the implementation platform is the combination of substantial hardware and software components that provide an environment under which the prototype software application may be run. As a Web-based platform, the client of the system is a Web browser run under a Windows operating system. The Internet Explorer (IE) from Microsoft has been utilised in the developed prototype in order to access the 3D contents and the functionality of the three-dimensional virtual environment. It is today's most popular Internet browser, and it is used by about 76% of the users (see Figure 73). IE was introduced in 1995 and passed Netscape in popularity in 1998.

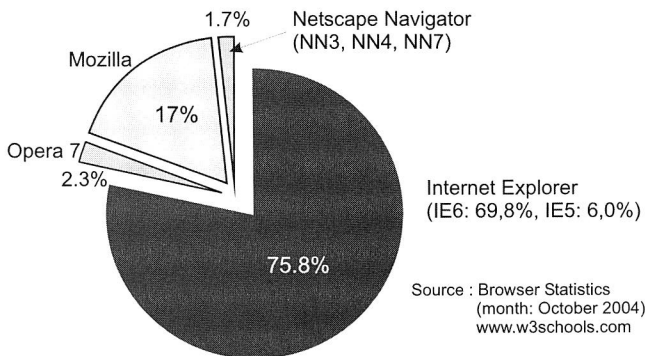


Figure 73: A statistics in browser usage

Another advantage of the Internet Explorer is its support for rich Web-based applications. They include Dynamic HTML (DHTML) features, which build a powerful user interface for the Web-based applications as well as support of Cascading Style Sheets (CSS), W3C Document Object Model (DOM) and Extensible Markup Language (XML).

To view 3D contents in the Web-based platform, the Internet Explorer must be able to embed a VRML browser. In this prototype, Cortona VRML Client from ParallelGraphics has been used for viewing 3D models on the Web. This software-plugin has a set of optimised 3D renderers, which guarantees the best visual quality on both PCs with the latest video-cards and those with more basic video card capabilities. In addition, the powerful Automation Interface allows adding exciting 3D capabilities to the Web application.

Another component of a Web-based platform, which manages the software application to be used, is the Apache Web server version 2.0. Apache has grown to be the most popular Web server on the Internet. The ability for a Web server to interact with external content-generating programs has been realised by the CGI (Common Gateway Interface) applications for Web by using PERL (Practical extraction and report language) in this prototype.

Viewing VRML files requires massive processing power, because every visible object in the scenes has to be rendered. For a smooth implementation, the hardware requirements such as PCs with high processing power and the latest graphics controllers, support modern 3D accelerators via DirectX and OpenGL. In this prototype, Intel Pentium IV with 2,8 GHz processor and an Intel® 82865G graphics controller have been used for the client PC.

7.2.3 VRML Techniques in the Development of the Prototype Software

When determining the requirements of assembly facilities, the aspects considered in general are *flow*, *space* and *assembly activities relationships* [153]. The flow mainly depends on the lot sizes, material handling equipment and strategies, layout arrangement and building configuration. Space is a function of the lot sizes, the storage system, the production equipment type and size, layout arrangement, the building configuration, etc. The relationships between assembly activities are defined by material or personnel flow, organisational structure and assembly process requirements. In this context, the layout plans of the assembly line are detailed representations of those assembly facilities. They include workplaces, machines, transfer and material handling systems, picking and storage systems, workers and other facilities. In the developed software, the assembly layout planning is represented three-dimensionally by using virtual models to provide a clear and easy understanding.

This section will discuss the VRML techniques that are utilised in the development of the Web-based prototype for layout planning of the assembly lines in detail. Using the VRML technique, Figure 74 shows a static representation of the assembly facilities. In

in this figure, *assembly_line* represents a high-level of the building block (*VRML node*) in the hierarchy. This node is a type of the grouping node and allows a list of children nodes, which are at a lower level of building block. The list of children nodes actually contains the collection of assembly facilities such as machines, workplaces and other resources in the assembly line model. The hierarchy of these nodes is also defined in the VRML as a *scene graph*.

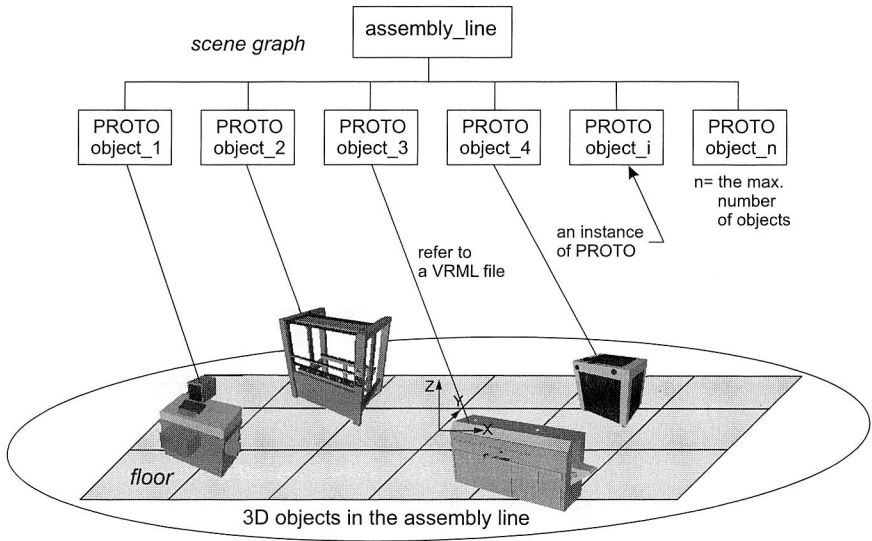


Figure 74: A scene graph of the assembly facilities to represent a layout planning problem

The children nodes (e.g., *object_1*, *object_2*), as presented in Figure 74, are instances (new copies) of the PROTO mechanism (short for prototype). This is a mechanism, which extends the set of node types within a VRML file. The PROTO mechanism is declared by a PROTO statement, which defines a new node type in terms of already defined (built-in or prototyped) node types. Once defined, the new node type can be instantiated in the scene graph exactly like the built-in node type. In addition, PROTO statement allows the definition of customised nodes. A customised node is a prototype and a combination of standard VRML nodes.

In order to meet the layout planning problems in the virtual environments, an instance of the VRML prototype (prototyped node) should have the following features:

- The prototyped node associates with any VRML file which represents a 3D object from the assembly facilities model

- A 3D object within the prototyped node is editable by using the pointing-device sensors, e.g. *TouchSensor*, *PlaneSensor* or *CylinderSensor*
- The attributes of the prototyped node e.g. translation, orientation and scale have the capability to receive or generate events in order to change their values. The change of those attributes values is displayed on the virtual environment as a transformation of the 3D object.
- The prototyped node allows a collision detection, if its attribute option is *enabled*

Once declared, a VRML prototype can be used like any standard VRML node in the scene graph. Class and type specifiers can be assigned to a prototype with arbitrary names. Therefore, the prototypes do not need to be in the same VRML file and they can be referred externally by using the `EXTERNPROTO` statement.

A `PROTO` statement consists of the `PROTO` keyword, followed in order by the prototype name, prototype interface declaration and prototype definition (as a body of the prototype). Its syntax is composed of the following:

```
PROTO <name> [ <interface declaration> ] { <definition> }
```

The prototype interface declaration defines the *fields*, *eventIns* and *eventOuts* for the new node type. The interface declaration includes the types and names for the *eventIns* and *eventOuts* of the prototype, as well as the types, names, and default values for the prototype's *fields*. The interface declaration may contain *exposedField* declarations, which are a convenient way of defining *field*, *eventIn*, and *eventOut* at the same time.

A prototype definition consists of one or more nodes, nested `PROTO` statements and `ROUTE` statements. Nodes in the prototype definition may have their *fields*, *eventIns* or *eventOuts* associated with the *fields*, *eventIns* and *eventOuts* of the prototype interface declaration. This is accomplished by using `IS` statements in the body of the node. In addition, a prototype definition can include a *Script* node. This node associates with the programming language codes in order to advance complex behaviours of the prototype. The execution of a full-featured programming language that carries out the *Script* node's function will refer to the *url* field.

PROTO Object [

eventIn	SFString	set_sensorType
eventIn	SFVec3f	set_skalierung
eventIn	SFVec3f	set_position
eventIn	SFRotation	set_orientation
eventIn	SFString	set_adr
eventIn	SFBool	set_collide
eventOut	SFVec3f	skalierung_changed
eventOut	SFVec3f	position_changed
eventOut	SFRotation	orientation_changed
eventOut	SFString	sensorType_changed


```

exposedField MFNode      children      []
exposedField SFVec3f     skalierung    1 1 1
exposedField SFVec3f     position      0 0 0
exposedField SFRotation  orientation   0 1 0 0
exposedField MFString    adr           ""
field SFInt32    obj_number 0
field SFVec2f    maxPos     20000      20000
field SFVec2f    minPos     -20000     -20000
field SFVec2f    maxH       0           4000
field SFVec2f    maxSk1     .001       100
field SFVec3f    offsetPS   0 0 0
field SFVec3f    offsetHS   0 0 0
field SFFloat    offsetCS   0
field SFString   sensorType ""
field SFBool     isCollide  FALSE ]
{...
    (prototype definition)
    ...
    DEF Scr Script {
        ...
        url ["javascript:
            (a set of functions by using JavaScript codes) "]
        (ROUTE statements)
    }
}

```

*Listing 2: A PROTO statement with prototype name **Object***

A PROTO statement, which represents the concept of 3D objects in the assembly line model for layout planning, is presented in Listing 2. The PROTO's name is **Object** and this PROTO contains numerous interface declarations. In order to indicate a change or user action, receive events from other nodes or contain a program module that performs some operations, a *Script node* is included in the prototype definition. The codes in the Script node are written by using JavaScript. They provide all requirements in order to perform a layout-planning task in a virtual environment.

The PROTO mechanism must be defined once again in an external file as EXTERN-PROTO in order to instance the PROTO statement into prototyped nodes (see Listing 3). In the EXTERNPROTO definition, the DEF keyword instantiates a prototyped node with the node's name. This node represents an object from the assembly facilities/resources in the virtual environment.

In Listing 3, **assembly_line** is considered to be the high-level of the building block (node) in the VRML hierarchy. The lower level of the building block consists of a collection of prototyped nodes, which are instantiated from a PROTO statement. For instance, `DEF Object_3 Object{ }` means that `Object_3` is the name of a prototyped node,

which is instantiated by a **PROTO Object**. Initially, this prototyped node is empty, i.e. no specific 3D model or attributes are referred within it. This value is considered as the default value of the prototyped node. In addition, the maximum number of the prototyped node is equivalent to n . In this work, the VRML programming technique in Listing 3 is applied to describe a model for layout planning problems of assembly lines in virtual environments.

```
EXTERNPROTO   Object [
...
(the content is the same as in the prototype declaration)
...
] "object.wrl#Object"

DEF assembly_line
  Transform { rotation 0 1 0 0
    children [
      DEF Object_1   Object { }
      DEF Object_2   Object { }
      DEF Object_3   Object { }
      DEF Object_4   Object { }
      DEF Object_5   Object { }
      ...
      DEF Object_n-1 Object { }
      DEF Object_n   Object { } ]
  }
```

Listing 3: A VRML model for layout planning problems

Each of the prototyped nodes defined in Listing 3 has its properties or attributes, which are a set of fields. Fields may contain various kinds of default values. Manipulating this node (e.g. assigning a VRML object and moving it into the virtual environment) causes dynamic change of the field's values. These fields' values may be the position, orientation and scale values, types of VRML sensors to be used (as string), collision detection value (as BOOLEAN), etc.

```
DEF object_1   Object {
  adr           "ressr/placement_machine.wrl"
  sensorType    "tx"
  position      -5100 -1020 0
  orientation    0 1 0 0
  skalierung    1 1 1
  isCollide     TRUE }
```

Listing 4: A prototyped node with the attributes and their values

Listing 4 shows a prototyped node with its attributes in VRML. The node represents a 3D object from the placement machine in the virtual environment. The absolute machine

position is $X: -5100, Y: -1020, Z: 0$; the movement along the X -axis as well as the collision detection are enabled, and the model has the original dimension (scale factor has default value). Actually, the node attributes are dynamic and the field values can change depending on the actions (events) that the object receives/sends.

7.2.4 Transformation of 3D Objects in the Virtual Environment

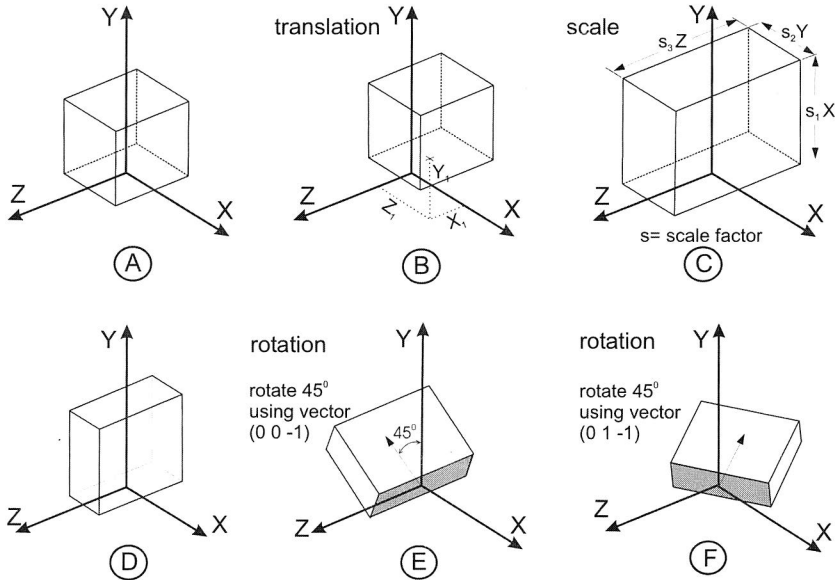


Figure 75: Transformation of 3D objects in a VRML coordinate system

Transformations of a 3D object in the virtual environment refer to the change in position, orientation and shape size of the 3D object. VRML has a geometric transformation called *transform* node, which can be used to perform scaling, rotation and translation within a coordinate system.

Translation allows placing a 3D object in any point of the coordinate system. Furthermore, a vector and an angle define a rotation. The vector specifies the axis of rotation, whereas the angle specifies the amount to rotate in a counter clockwise direction. Figure 75 (D) shows a box in its default position, (E) a box rotated by 45 degrees around the Z -axis by using vector $(0\ 0\ -1)$ and (F) a box rotated by 45 degrees by using vector $(0\ 1\ -1)$. In addition, a scaling operation in Figure 75 (C) allows resizing the original box dimension. Enlarging or decreasing the size of a shape in any number of dimensions is also possible, as long as the scale factors are positive.

The capability to transform 3D objects in a virtual environment is a core function in the developed software prototype. Each of the assembly line resources should be able to be assigned in the virtual environment and then to be translated, rotated or scaled for layout planning. This capability is controlled from an external application (Web application) in order for the remote user to have a multiple, simultaneous and distributed access to the project data including 3D layout of complete assembly lines.

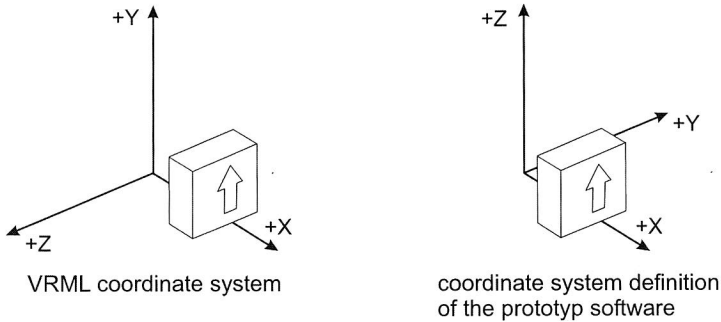


Figure 76: Two coordinate systems

The VRML coordinate system uses the right-handed Cartesian coordinate system. If the thumb, index finger, and middle finger of the right hand are held so that they form three right angles, then the thumb symbolizes the X-axis as horizontal axis, the index finger stands for the Y-axis (pointing upward or vertical axis) and the middle finger for the Z-axis (coming out of the screen).

In contrast to the VRML coordinate system, the coordinate system of the prototype software uses the Cartesian coordinate system, whose vertical axis related to the Z and the Y-axis lies on the horizontal plane coming in from the screen (see Figure 76). This coordinate system definition intends to provide a more convenient appearance for the user, since most of the CAD coordinate systems use this definition.

The different definitions of the coordinates systems result in the requirement to redefine the convention from the coordinate system of the prototype software in the computer screen compared to the original VRML coordinate system. In this case, +Y and +Z axis in VRML coordinate system should be correspondingly redefined as +Z and -Y-axis in the software prototype. This convention is also based on the right-handed Cartesian coordinate system.

Getting the position values of a selected object

This sub-section provides a short discussion about the detection of the actual position values of a selected object in a VRML scene and the display of these values on an HTML page (Web application). In order to obtain the actual position of a selected object, an interfacing process between a VRML scene and an HTML application environment is

needed. The API technologies (VRML Automation) from Cortona SDK provide this kinds of interfacing process. The following procedure illustrates this interface process in order to set and display the position values of the selected 3D object.

- Create a new field object of the *SFVec3f* data type as a temporary object, which represents the X, Y and Z values of a position in a three-dimensional space.

```
var pos=Scene.Engine.CreateField('SFVec3f');
```

- By clicking on the selected object, the current position value in the VRML scene has been obtained and the position value (*SFVec3f*) has been assigned to the temporary object.

```
pos.Value=Scene.Engine.Nodes("Obj"+current).Fields("position").Value;
```

- Return the temporary field object into X, Y and Z floating-point values. These values indicate the current position data in the coordinate axes. A redefinition between two different coordinate systems must be considered.

```
var x=pos.X; var y=-pos.Z var z=pos.Y;
```

- The current position data will then be set into *input types* and must be enclosed within a *form* element in an HTML page. Thus, the position values of the selected object will be displayed on the HTML application.

```
var position_value= top.navig.document.forms[0];  
position_value.xa.value=x;  
position_value.ya.value=y;  
position_value.za.value=z;
```

A similar procedure has to be conducted in order to get the rotation values of a selected object. In case of rotation, the rotation field is a *SFRotation* data type, which accepts floating values that correspond directly to X, Y and Z and the angle components. The rotation value that is measured in radian by default must be converted into degrees.

Transformation of the selected object by using Sensor nodes in the VRML scene

Transformation of a 3D object in a VRML scene such as moving the object, changing the object's orientation or scaling the object in this prototype software can be done by several means:

- Dragging the selected object in the 3D View window (current 3D scene which is displayed on the HTML page) with the mouse,
- Setting the numerical values on the 3D Tool panel to specify translations, rotation or scale in the X, Y and Z directions in millimetres,

- Using the “+” or “-” keys to set a new translation, rotation, and scale on the 3D Tool panel incrementally.

Firstly, the discussion takes on a procedure for selecting the objects in the virtual environment and activating a corresponding *Sensor* node for the selected object. It begins by clicking a 3D object in the 3D View window. Subsequently, a corresponding transformation (e.g. move object in XY plane) is selected on the 3D Tool panel. This process will activate a function `sensor(sT)` and produce a sensor type. By means of an interfacing mechanism, this value is set to activate a corresponding *Sensor* node in the VRML scene graph (see Figure 77).

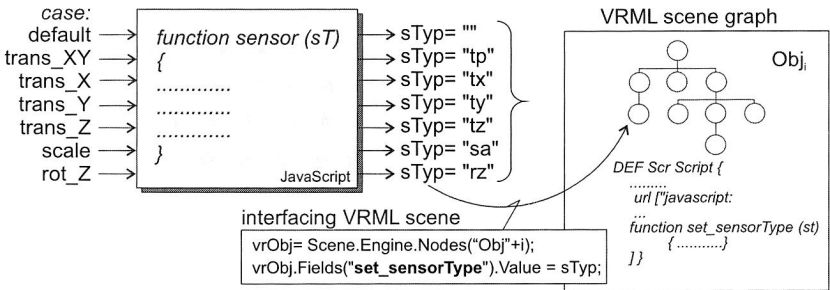


Figure 77: An interfacing mechanism for activating a *Sensor* node in the VRML scene graph from HTML application

The dragging of 3D objects in the 3D View window utilises *Sensor* nodes, which are provided by VRML (e.g. *PlaneSensor*, *CylinderSensor* and *TouchSensor*). The procedure begins with selecting a 3D object and then activating a corresponding sensor type. Routing an event output generated by an activated *Sensor* node to an object node, and receiving the event to set its position or rotation, gives the impression of moving the object in a certain direction or of changing the object's orientation in the virtual environment.

Transformation of a 3D object in a VRML scene by means of setting the numerical values on the 3D Tool panel utilises an interfacing mechanism that uses a set of interfaces from the VRML Automation (see Section 7.2.1). The procedure begins with selecting the object to be transformed by clicking a 3D object. The new transformation is achieved by choosing any transformation, e.g. moving in XY plane, rotating around Z-axis or scaling in Y-axis, and storing the floating values on the 3D Tool panel by user. By means of interfacing mechanism, these values will substitute the corresponding attribute values of the selected object in the VRML scene graph. Thus, the selected object is transformed.

A similar procedure is considered to perform a 3D object transformation incrementally by using the “+” or “-” keys. In this case, an incremental value has been given in advance, which will affect every event produced by the user.

7.2.5 Three-Dimensional Objects Library

This Web application requires the library system for 3D objects (see Figure 78), which enables the user to easily navigate and organise objects along with their information and graphics. The dynamic tree navigation system is utilised for navigating through the objects. It allows the user to navigate through the tree and to expand and collapse tree branches without repeated trips to the server. An object that has been chosen in the tree navigation system will display its information as well as corresponding graphics in the VRML scene.

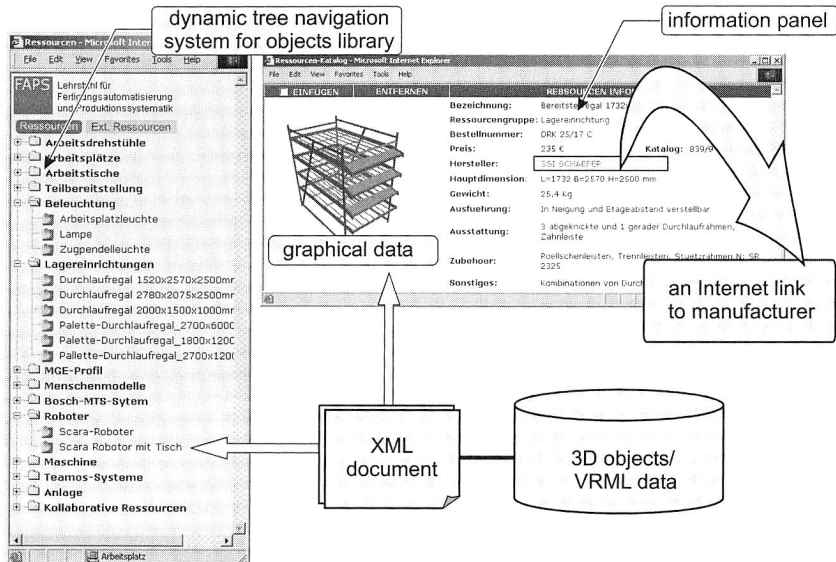


Figure 78: A three-dimensional objects library for the Web application

The following Web technologies have been applied to build up the 3D objects library in the Web application (HTML page):

- XML - stores data used to build the tree,
- DOM - defines the logical structure of documents and the way a document is accessed and manipulated,
- JavaScript - controls the expanding/collapsing of menu items.

The dynamic tree navigation system builds a tree by using data stored in a properly structured XML file. Using an XML file to store the content of the menu gives developers the ability to easily update the tree menu by modifying the XML text file. Figure 79 depicts an XML tree structure, which stores data of the objects library for layout planning.

An XML tree structure is a type of data structure in which each element is attached to one or more elements directly beneath it. It allows for context relationships between elements in an XML document to be expressed in any level of complexity.

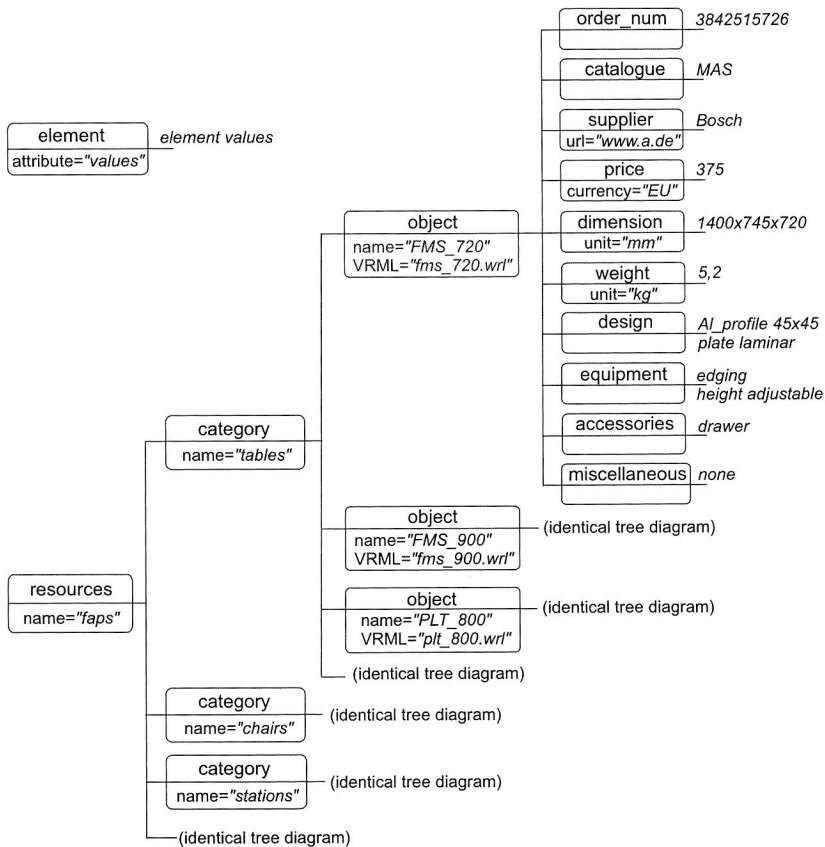


Figure 79: XML tree structure for objects library

In the XML tree structure, `resources` is the highest level in the structure hierarchy. It consists of child structures, which are a number of `category` elements. These elements classify the assembly facilities, which are represented by an `object` element that has the attributes `name` and `VRML`. The attribute `name` works as an identification for the 3D object in the library list, whereas the attribute `VRML` refers to a VRML file of a 3D object. Several sub-elements are attached to the `object` element, which operates as information for the object. The sub-elements include order number, catalogue, supplier, price, dimension, weight, design, equipment, accessories and a miscellaneous

element. The XML document that contains the assembly facilities can then be created according to this structure.

A three-dimensional objects library is a Web application, which consumes the XML document. This client-side application parses, processes and interprets the XML document. Once the XML file is successfully loaded into the parser, it builds a Document Object Model (DOM) tree from the events it receives from the parser. It defines the logical structure of documents and the way a document is accessed and manipulated. DOM is a platform-neutral interface that allows JavaScript DOM APIs to dynamically access and update the content, structure and style of the XML document. Subsequently, JavaScript DOM APIs manipulate and generate the XML document as an objects library in the HTML application

In addition to the objects library in the server, the system may also involve other 3D objects as external libraries from remote locations outside the server (see Figure 80). Thus, resources from customers, partners or suppliers can be integrated in the system and can be used for planning processes. External libraries consist of XML documents along with VRML 3D objects that are located on third-party servers. The fetched 3D objects from the external server are localised into the additional tree navigation system in the objects library panel.

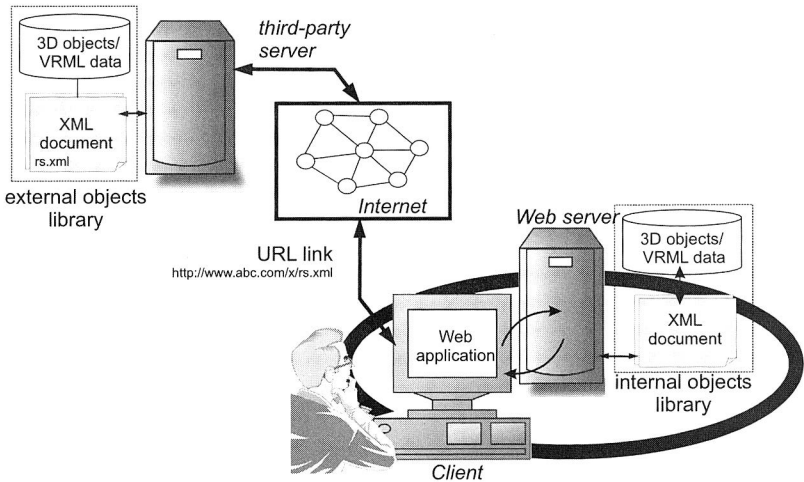


Figure 80: External objects library

7.3 Software Implementation for Layout Planning of the Assembly Lines

A Web-based software prototype, which has been developed in this work, is implemented for layout planning of assembly line facilities. The prototype software provides a virtual collaborative environment over the Internet which allows simultaneous and distributed access to the 3D layout design of complete assembly lines, particularly manual working environment among multiple parties in different locations. The prototype software is a part of the software @WebPlan, a Web-based application for planning assembly systems.

7.3.1 Implemented Features

The prototype software for the layout planning of assembly lines is shown in Figure 81. The procedure begins with defining the assembly floor area by using a dialogue box. Subsequently, the user can jump to the main software area, where the prototype software implements the following features:

- Changing the viewpoints in the 3D View window
- Adding and removing the objects to/from 3D View window
- Moving, rotating and resizing the objects
- Marking the objects
- Centring the objects
- Collision detection between objects
- Interactive 3D objects with complex behaviour
- Ruler object
- Listing the objects
- Management of the project files
- Online library for the 3D objects

The following description provides a further explanation of the implemented features.

Changing the viewpoints

A View panel is responsible for changing the viewpoints. The panel employs the “*camera*” metaphor in order to display several views in the 3D View window. Several cameras retain its viewpoint and each of the cameras is controlled by the interface elements in the View panel. By clicking on the interface elements in the View panel with the mouse, the corresponding viewpoint will be switched to the other view (e.g. front view, top view, isometric view, etc), showing the movement in the 3D View window.

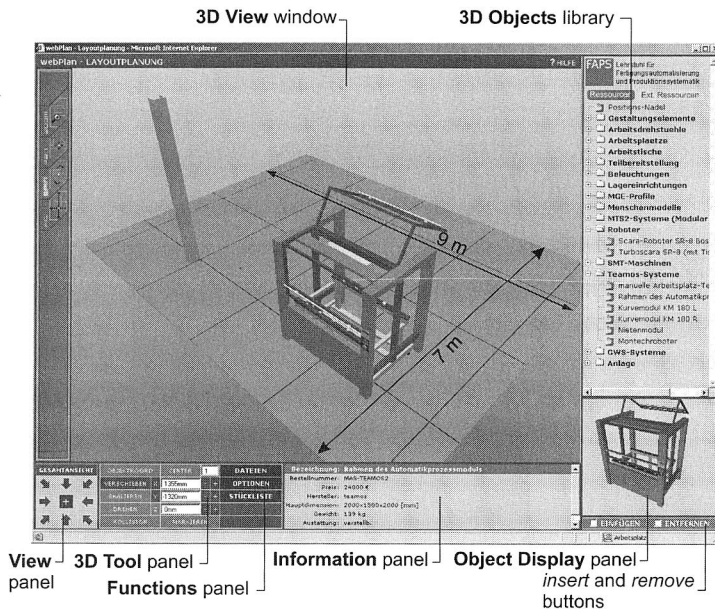


Figure 81: Web-based prototype software for the layout planning

Adding and removing the objects to/from a 3D View window

When an object from the objects library is selected, the 3D graphic model is visualised on the Object Display panel. In order to insert the selected object into the 3D View window, the button “insert” needs to be pressed. By default, the object will stay on the origin point of the global coordinate system. In return, the object in the 3D View window can be removed by using the “remove” button followed by a click on the object.

Moving, rotating and resizing the objects

A 3D Tool panel performs these functions. A 3D object, which will be transformed, should be in the edit mode. This mode is active, if either a new object is added or an object is directly clicked on in the 3D View window. Figure 82 depicts the 3D Tool panel, where the functions of moving, rotating and resizing the 3D objects are available.

In the prototype, moving or turning an object could be performed either by directly dragging the selected object on the 3D View window or by inserting the numerical values into the 3D Tool panel. In addition, an incremental move or rotation can also be controlled by the “+” and “-” keys. Any of the object’s six degrees of freedom can be locked, thereby inhibiting movement or rotation in that direction.

☞ case 1: editing mode inactive

VERSCHIEBEN	X	<input type="text"/>	-	+
SKALIEREN	Y	<input type="text"/>	-	+
DREHEN	Z	<input type="text"/>	-	+

☞ case 4: move in the Z direction

VERSCHIEBEN	X	<input type="text" value="456mm"/>	-	+
SKALIEREN	Y	<input type="text" value="-1350mm"/>	-	+
DREHEN	Z	<input type="text" value="1200mm"/>	-	+

☞ case 2: move in XY plane

VERSCHIEBEN	X	<input type="text" value="456mm"/>	-	+
SKALIEREN	Y	<input type="text" value="-1350mm"/>	-	+
DREHEN	Z	<input type="text" value="0mm"/>	-	+

☞ case 5: rotate in the Z direction

VERSCHIEBEN	X	<input type="text" value="0°"/>	-	+
SKALIEREN	Y	<input type="text" value="0°"/>	-	+
DREHEN	Z	<input type="text" value="40°"/>	-	+

- and + keys
to set a new
rotation

☞ case 3: move in the Y direction

VERSCHIEBEN	X	<input type="text" value="456mm"/>	-	+
SKALIEREN	Y	<input type="text" value="-2100mm"/>	-	+
DREHEN	Z	<input type="text" value="0mm"/>	-	+

- and + keys
to set a new
translation

☞ case 6: scale in the X, Y, and Z directions

VERSCHIEBEN	X	<input type="text" value="1.5x"/>	-	+
SKALIEREN	Y	<input type="text" value="0.9x"/>	-	+
DREHEN	Z	<input type="text" value="1x"/>	-	+

- and + keys
to set a new
scale

Figure 82: Move, scale and rotate a 3D object in a 3D Tool panel

The change of an object's width, height and depth is supported either with numeric input or controlled by the "+" and "-" keys, having no direct dragging capability on the 3D View window.

Marking the objects

This feature can mark a 3D object in the 3D View window. The position data of a marked object is then highlighted in the status bar. If a marked object is moved in a certain direction, the actual position as well as the distance between the actual position and the marked position will be displayed in the status bar (see Figure 83).

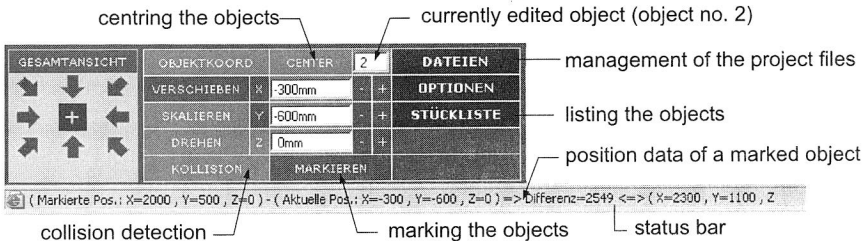


Figure 83: Several features of the 3D Tool and Function panels

Centring the objects

This feature is utilised for centring the coordinate system of the 3D objects. The 3D objects originating from VRML files are converted without consideration of the centre point. Mostly, they are not correctly placed in the centre of the object. Consequently, later on, the object cannot be rotated correctly according to its centre axis. This feature computes the main dimension of the object and determines its coordinate centre.

Collision detection between objects

The prototype software supports object-to-object collision detection. Object-to-object collision detection in a three-dimensional scene is a procedure for determining whether a given shape, if it were to undergo some transformation (for example, to be moved, rotated or scaled), would encounter an obstacle in the form of another shape.

This allows putting a 3D model of an assembly facility right beside another one in the assembly line. This feature is quite important when arranging the details of the assembly line resources. By default, collision detection is switched off and this option can be switched off/on by pressing the button "collision detection" on the 3D Tool panel.

Collision detection does not work at the time, when an object is being dragged-and-dropped into a scene. So the object may cut into an obstacle, and it will not be possible to move it. In order for the object to be moved, the collision detection has to be switched off. After the object has been moved, the collision detection can be switched on again to position the object more exactly.

Interactive 3D objects with complex behaviour

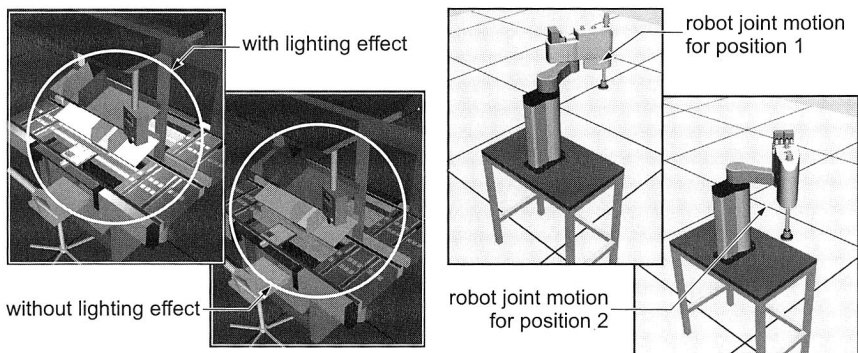


Figure 84: Interactive 3D objects with complex behaviour

Lighting effects, altering robot joints and routing the workplaces over band conveyors, are examples for interactive 3D objects with complex behaviour. To deliver such features, the prototype utilises the Internet Scene Assembler (ISA) developed by Parallel-

Graphics. It provides a platform independent file format that can store not only its standard objects and attributes but also custom defined ones.

Figure 84 depicts some of the features mentioned above. The manipulate segment, e.g. switching on/off lamps, produces the lighting effect in the workplace. Another example is the manipulated translation and rotation motions of SCARA robot arms in the 3D View window. As for whole objects, any of a segment's six-degree of freedom could be locked, and a range constraint could also be defined by setting a minimum and a maximum value.

Ruler object

A direct manipulation tool using a „ruler object“ carries out the measuring of a metric distance between two arbitrary points. After the first point has been selected, a „*ruler object*“ is dragged with a mouse to the second point. The distance between two points is computed manually. In case of measuring the distance between the two assembly facilities, the „*ruler object*“ is used together with the mode *enabled* for collision detection in order to obtain an accurate point position.

Listing the objects

A list of the objects is one of the features, provided by the software prototype. All of the 3D objects of the assembly facilities, which are inserted into the 3D View window, are submitted to the list of the objects (see Figure 85). This list is composed of several columns for object items such as the designation, order number, catalogue, price, manufacturer, dimension or weight of the object.

STÜCKLISTE										
Nr.	Bezeichnung	BestellNr.	Katalog	Preis	Hersteller	Dimension	Gewicht	Ausstattung	Zubehör	Sonstiges
1	Durchlaufregal_152x257x250	3842515712	-	1135	P.+K.Lagertechnik GmbH	L=1520 B=2570 H=2500	8,2	verstellb.	-	abgeknickte, 1 gerader Durchlaufrahmen
2	Durchlaufregal_152x257x250	3842515712	-	1135	P.+K.Lagertechnik GmbH	L=1520 B=2570 H=2500	8,2	verstellb.	-	abgeknickte, 1 gerader Durchlaufrahmen
3	FMS Arbeitstisch	3842515573	mas seite 1-6	1426	Bosch-Rexroth	L=1200 B=600 H=1000	5,1	verstellb.	-	Alu-Profil 45x45, Platte: Laminat, antrieflex
4	Pultarbeitstisch	3842515571	mas seite 1-6	1526	Bosch-Rexroth	L=1000 B=600 H=1000	13	verstellb.	-	Alu-Profil 45x45, Platte: Laminat, antrieflex
5	Rahmen des Automatikprozessmoduls	MAS-TEAM052	-	24800	teamos	2000x1500x2000	139	verstellb.	-	-
6	Besteckmaschine (Siplace HF)	SIPLACE HF	Siemens Dematic	-	Siemens_Dematic	L1400x81000xH 1400	124 Kg	TwintHead	collect & Place Kop	Bestückleistung von 17.000 Bauelementen
7	Stuhl h=450 mm	3842352070	mas seite 1-6	202	Bosch-Rexroth	400x400x500	4,2	verstellb.	lehne	-
8	Stuhl h=650 mm	3842352077	mas seite 1-6	327	Bosch-Rexroth	400x400x600	4,7	sicherheitsarmlehnen 384235207	lehne	-
9	EDV-Arbeitsstuhl	ws1820	Industriestuehle	273	Werkstz	min. Hoehe 450	4,1	Sicherheitsgastfeder	Sicherheitsringarm Nr.:011.16	-
10	Halogen-punktleuchte	3.13-11	-	126,6	MAYTEC	-	0,2	-	-	-

Figure 85: List of the assigned objects from the assembly facilities

Management of the project files

In this prototype software, a project file consists of the following categories:

- object (identifier abbreviation “*obj*”). It represents an individual 3D object of assembly facilities in the VRML file (extension *wrl*)
- resources (identifier abbreviation “*res*”). It represents a collection of 3D objects of assembly facilities (e.g. objects library from manufacturer “X”) in the XML file (extension *xml*)
- project (identifier abbreviation “*prj*”). It represents a project data, which is the result of the prototype software. The format of the project files is either an XML or a VRML file type. In addition, the project files can be saved temporarily as data in form of cookies in the client browser.



Figure 86: Management of the project files

The project files are located in a public folder on the Web server. The dialog box “management of project files” (see Figure 86) provides several functionalities to manage several project file categories as mentioned previously. These functions and their task are as follows:

- **Open:** the process to open any previously saved project file in the server in form of cookies (Open-project cookies) and XML files (Open-project XML file). External objects libraries (formatted in XML and VRML), which are located on other server systems can also be displayed from the client area by using this function (Open-external resources). This action is followed by the creation of a dynamic navigation system in the 3D objects library. These open options (i.e. as cookies, project file, or external resources) can be selected in the file type.

- **Save:** the process to store a current project file on the Web server for future use. Saving a layout-planning project could be conducted temporarily in form of cookies data in the client browser. Normally, the saving of a project on the Web server uses either a VRML or an XML file type. In addition, the external object library can also be saved in the public user directory on the server for further uses (Save-external resources).
- **Upload:** the process of transferring one or more files from a local source to a Web server to make the file available to others. This function enables the VRML and XML file type from the local machine to be located on a Web server.
- **Download:** the process of transferring one or more files from a remote computer (e.g. Web server) to the local computer (the opposite action is upload). This function enables the project files (VRML and XML file type) to be run/revised in the local machine.
- **Rename:** the process to give a different file name to a file on the Web server
- **Delete:** the process to remove a selected file, e.g. an object, resource or project file from the Web server.

Online library for 3D objects

This feature enables the user to easily navigate and organise objects along with their information and graphics. It is a dynamic tree navigation system that allows the user to navigate the tree and to expand and collapse tree branches without repeated trips to the server. An object that has been chosen in the tree navigation system will display its information in the Information panel as well as its graphical representation in the Object Display panel.

Another important feature is the capability to load an external object library from another server to the client machine, i.e. the Web application. This feature is activated by the *"open file-external objects library"* function in the management project file (see Figure 83). The external objects library should have the same format data (XML file) along with VRML objects. After loading and processing the XML file from another server, the same dynamic tree navigation system for the external objects will be prompted in the same panel. Using the button *"resources"* and *"external resources"*, the user can switch between the two libraries.

7.3.2 Block Layout for the Rough Layout Planning

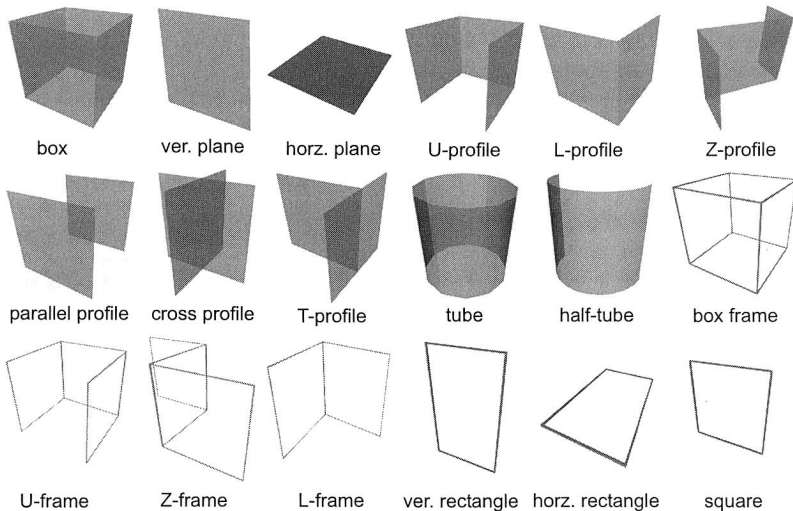


Figure 87: Several scalable geometries for block layout

The a top-down approach, which allows a stepwise planning method from rough to detailed layout planning, carries out the implementation of the Web-based prototype for the layout planning of the assembly lines. The rough layout of the assembly lines begins with a block layout. The whole assembly area, e.g. pre-assembly, final-assembly or the space required for stations or machines, is represented as blocks. Therefore, several scaleable basic geometries shown in Figure 87 are needed for this purpose.

The 3D objects are available from the objects library on the Web server. These objects are assigned to an objects library under the category “*configuration element*”. They serve as resizable geometries (in width, height and depth) for rough layout planning. The user can interact with the selected objects by activating the scaling manipulation mode in the *3D Tool* panel. Step by step, the model within the blocks will be refined in detail, until the assembly line and workstations are identifiable.

Figure 88 shows a block layout for an assembly line. The building wall and the columns as well as the area distribution and partition to the footpath area have been created and manipulated by using the “*configuration element*” objects from the library. In this stage, the processing stations (e.g. manual workplace, machines), puffer, warehouse, storages and retrieval systems, etc. are presented as block layout.

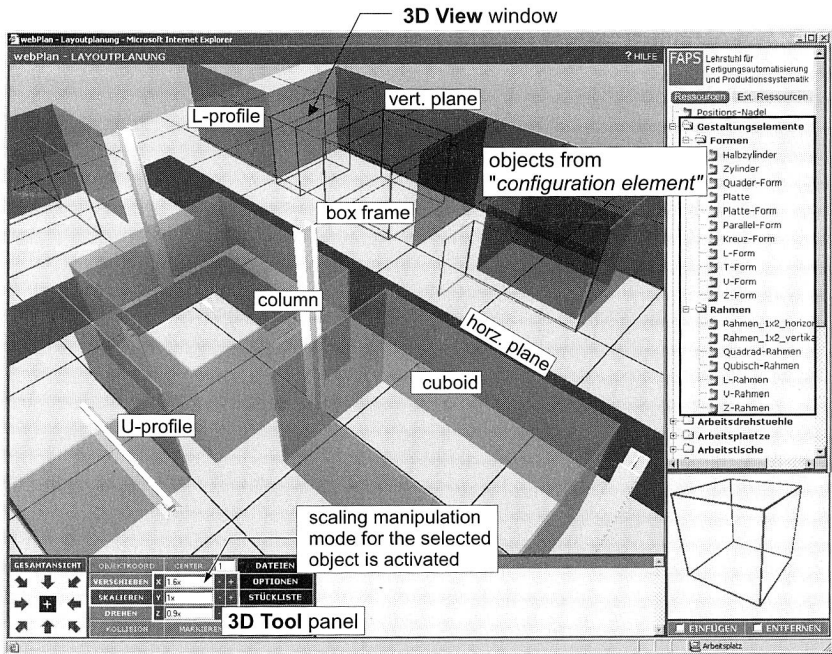


Figure 88: Block layout by means of scaleable 3D objects for the rough layout planning

To deal with the "configuration element" objects, the user should add these objects to the 3D View window to allow them to be operated via 3D Tool panel. Subsequently, the *scale* operation will be activated for the selected object. To resize the object, e.g. into cuboids, box frame, the user should either type the desired scale values into the edit-boxes and then click the corresponding directions (the X, Y or Z buttons) or control the value by the "+" and "-" keys.

7.3.3 Detailed Layout Planning

In the detailed phase, the whole assembly area along with the marked areas in blocks for several facilities needs to be modelled in detail. Using the component models e.g., work tables and chairs, live storage racks, conveyor systems, machines, etc. from the objects library on the Web server or other components from external objects libraries from third parties, the detailing process can be performed efficiently. Special components can be imported from other CAD systems in form of VRML files on the local computer and then uploaded to the Web server for detailed layout planning purposes. The detailed process for individual manual workplace and the usage of human models and ergonomic considerations will be explained in detail in Chapter 8.

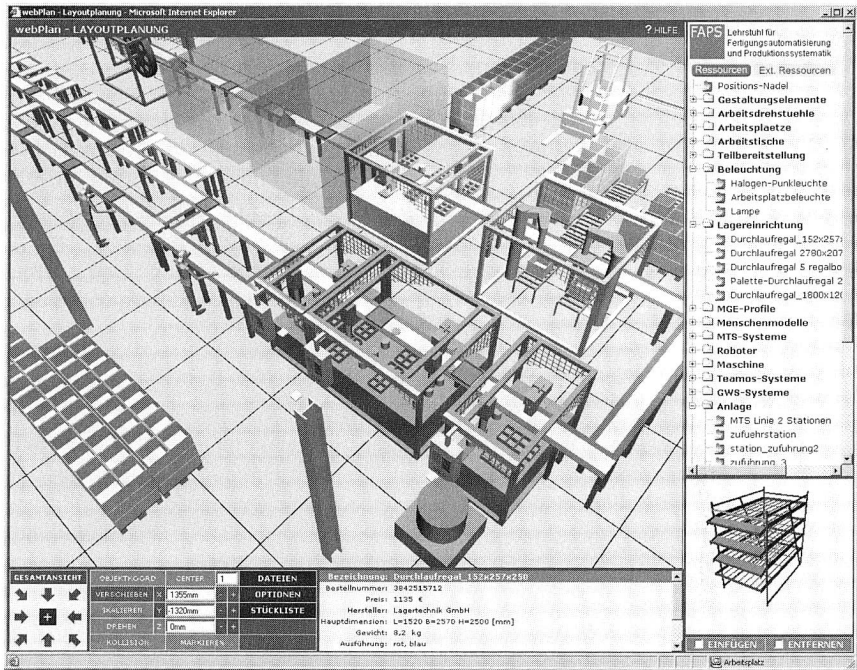


Figure 89: Detailed layout planning of an assembly line by using this prototype software

Figure 89 depicts a detailed layout planning for an assembly line, which consists of conveyor transfer systems, manual workplaces, automatic stations and buffer systems. This Web-based application provides an environment for collaborative layout planning of assembly lines. Generally, the planning processes like information sharing and exchange of ideas among multiple parties in different locations and at different times can be conducted by using the software prototype. Furthermore, this Web-based application for layout planning also supports concurrent engineering during the production development time. The software prototype is a solution that provides remote users with multiple, simultaneous and distributed access to the project data including a 3D layout of the complete assembly lines and particular working environments for manual workplaces. The online environment with 3D capabilities allows parties in different locations to speed up the exchange of ideas, to reduce misunderstandings and to facilitate problem solving and as a result significantly improve the collaborative design process.

8 Development of a Web-based Prototype for Layout Design of Manual Assembly Workplaces

This chapter focuses on the development of a Web-based prototype for the layout design of manual assembly workplaces, which is a part of the modules in @WebPlan. The development of such a Web-based application in a virtual three-dimensional environment involves the activities of creating a three-dimensional environment for layout design over the Internet, modelling of humans, the development of Web-based tools for workplace and ergonomic analyses as well as a Web-based tool for time measurement for manual works. In addition, the implementation of a prototype for designing manual assembly workplaces will be shown in the end of this chapter.

8.1 A Review of Available Systems

A number of approaches for the design and planning of manual assembly workplaces from literature, have been developed. Bullinger [29] has introduced a systematic approach for assembly planning, including a detailed planning for manual assembly workplaces. Edward [43] has developed an MTM-based task time prediction model and a bio-kinematics human model for assembly workplace design. Braun et. al. [25] has reported a computer-aided planning system for designing and planning manual assembly systems, called EMMA (*Experte zur Gestaltung manueller Montagearbeitssysteme*). EMMA is based on AutoCAD and offers all the functions needed to simulate and record the assembly process. It is claimed that workplace layouts can be designed and evaluated with both ergonomic (human factors) and economic (assembly time and cost, MTM time analysis) considerations. Feyen et al. [51] have also developed software tools that allow ergonomics-related information to be accessed in the earliest stages of design. Augmented Reality technology also offers a new potential approach for industrial planning processes including layout design of manual workplaces. Using this technique, a physically existing workplace environment can be superimposed with virtual planning objects [132].

Several computer-aided systems have been developed for the design and planning of manual assembly workplaces. Most of them have been developed by using three-dimensional CAD programs with built-in ergonomics assessment capabilities. The systems also incorporate three-dimensional human models, which represent various anthropometries and postures, evaluative techniques to assess reach, vision, fit, and posture, and an interactive interface that allows designers to manipulate both the human form and the workplace design. Some of them possess some or all of the above features to varying degrees. They include RAMSIS [139], SAMMIE [126], APOLIN [58], Deneb/ERGO [122], ERGOMAN [90], JACK [10] and COMBIMAN [88]. However, these computer-aided systems with human models do not deal with the environment planning over the Internet, which enables a virtual layout design of manual assembly workplaces in a collaborative manner and can be controlled by remote users.

for VRML. A joint in this model can consist of one, two, or three DOF in rotational axes. For instance, the knee joints consist of one DOF (in X rotational axis), whereas the elbow joints are composed of two DOF (in X and Z rotational axes). A shoulder joint consists of three DOF. Each joint's DOF has a maximal and minimal angle value [40], [52]. An important joint is the loin, which is responsible for lateral bending and twisting of human postures. Both working postures in connection with the loin joints cause the most common injuries received in physical tasks performed by humans.

8.2.2 Human Modelling in VRML

To represent the human model in the three-dimensional environment, a modelling approach based on VRML has been developed. Figure 90 (right hand side) shows the structured nodes, which are arranged into a scene graph for VRML. The hierarchy of nodes in the scene graph indicates simplified human segments. Each of the segments in the scene graph has its corresponding joints and degrees of freedom as segment's attributes. As seen from this figure, a segment could obtain a child structure, which consists of other segments. When a transformation is created in one segment, it will affect all child structures including the segments and joints.

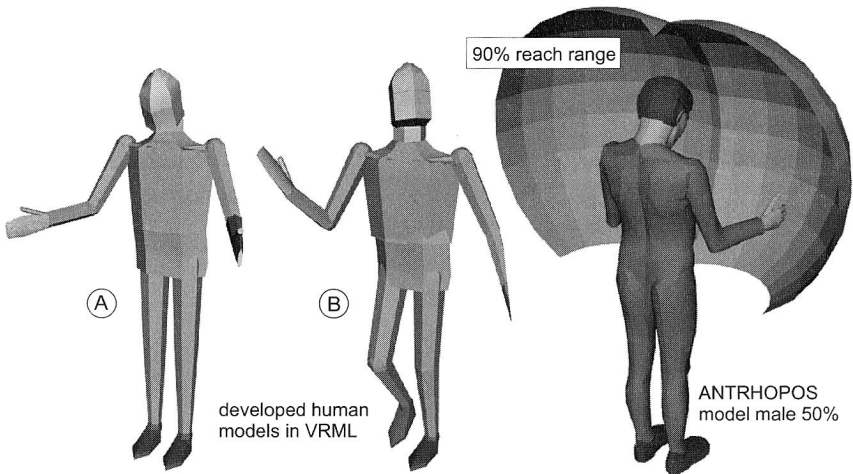


Figure 91: Human model developed in VRML compared with an Anthropos model (static), which is generated with a CAD system.

A set of *CylinderSensors* has been used to model and simulate joints in VRML. Each of the joint's degrees of freedom should obtain an individual sensor in order to control its specific motion constraint. To allow this capability in modelling human models, a joint, which consists of more than two degrees of freedom, uses additional "dummy segments", so that each segment controls a motion in a degree of freedom.

The development of the prototype of the human model in VRML utilises the Internet Scene Assembler (ISA) developed by ParallelGraphics to deliver an interactive 3D human graphics. This VRML authoring tool enables each object (segment and joint) to be endowed with certain abilities in the scene. In this case, joint motions according to the joints own degrees of freedom considering angle constraint are possible. Figure 91 depicts a prototype of the developed human model, which has been utilised for the design, and the layout of a manual workplace. Using a VRML sensor provided in this model, a specific body posture could be manipulated directly. In this manner, the existence of awkward postures occurring in the workplace can be evaluated in advance in the three-dimensional virtual environment. In addition, another human model (Anthropos model) has been utilised in this software prototype for both male and female models with 5th, 50th and 95th percentile. These models are static (segments and joints are not able to be manipulated) and also prepared with several types of reach range.

8.3 Web-based Tools for Workplace and Ergonomic Analysis

In order to perform design tasks for manual workplaces, a set of tools for workplace design and ergonomic analysis is required. These tools can be called from the main page of the prototype software by clicking “*checklist*”. This action will display a window frame as shown in Figure 92. The workplace and ergonomic analysis tools include the following features:

- Recommended workplace dimensions for productions according to DIN 33406
- Recommended dimensions of assembly workplaces according to TÜV Rheinland
- NIOSH lifting analysis
- Analysis of the lifting operations
- Analysis of the human postures

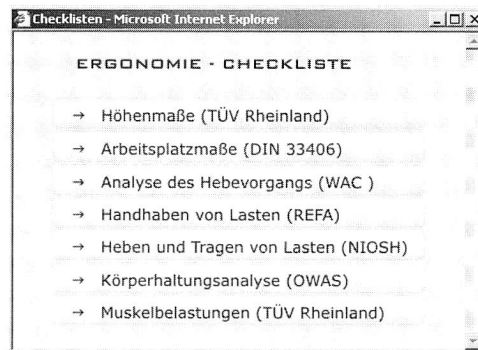


Figure 92: A list of the workplace and ergonomic analyses in the software prototype

8.3.1 Workplace Dimensions

DIN 33406 [103] is considered to be the standard for dimensioning workplaces in the production area, e.g. machines and assembly workplaces and includes the dimensioning of width, height and depth of workplaces. The workplace type to be dimensioned can be a sitting or standing workplace as well as a combined sitting-standing workplace. The determination of the recommended workplace dimensions is based on the geometrical dimensions of the human body given in DIN 33402 part 2 [102]. The human body dimensions in this standard cover the range from 5th to the 95th percentile for both men and women. In addition, other aspects to be considered are work requirements concerning visual control and coordination of fine motor activity. These aspects are categorised into high, average and low work requirements. For instance, packaging works have a low requirement concerning visual control and coordination of fine motor activity, whereas adjusting works have a high one.

A Web-based tool to determine recommended workplace dimensions for production according to DIN 33406 is shown in Figure 93. This self-developed tool is an integral part of the prototype software for layout design of manual workplaces. The results of this analysis are working height, sitting and footrest height, as well as thigh and leg clearance. Using this tool, the fitting of workplace conditions and job demands with the human body can be accomplished.

Arbeitsplatzmasse im Produktionsbereich nach DIN 33406

Arbeitsplatztyp:

- ☒ Sitzen
- ☐ Stehen
- ☐ Wechsel
- ☐ Hilfe

Sitz- Arbeitsplatzmasse

Arbeitsaufgabe: normaler Loharbeit

Arbeitsanforderungen: Hoch

Personenkreis: Favour

Arbeitsstellenhöhe C [mm]: 50

Arbeitsflächendicke K [mm]: 25

min. Fussstützenhöhe F [mm]: 0

min. Arbeitsflächenhöhe A [mm]: 920

Arbeitsflächenhöhe A [mm]: 950

Sitzhöhe S: von 500 mm bis 600 mm

Fussstützenhöhe F: von 30 mm bis 215 mm

Oberschenkelraum Z: ausreichend

min Oberschenkelraum Z: 5%, 140 mm; 95%, 195 mm

realer Oberschenkelraum Z: 5%, 325 mm; 95%, 425 mm

Beinraumbreite B: 550 mm

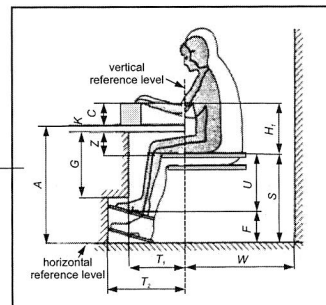
Höhe des Beinraums G: 350 mm

Beinraumbtie T1: 350 mm

Fussraumbtie T2: 550 mm

Bewegungsfreiraum D: 1000 mm

[Erklärung durch Bild]



a sitting workplace
and its dimensions

computing the workplace dimensions
for a sitting workplace over the Internet

Figure 93: Web-based tool to determine the recommended workplace dimensions for production according to DIN 33406 [103]

Another Web-based tool is used to determine the recommended height dimensions of the assembly workplace according to TÜV Rheinland. This method is designed particularly for assembly workplaces, and only available for seated and standing working posture. It contains 5 types of work and each of them has an ideal working height, which refers to the elbow height. For instance, assembling small parts (e.g. switches) or wiring works should be performed 10-14 cm above elbow height. A Web-based tool according to TÜV Rheinland has been previously shown in Figure 52.

8.3.2 Analysis of Manual Lifting

Low back pain (LBP) and injuries attributed to manual lifting activities continue to be one of the leading occupational health and safety issues. The work-related back injuries still account for a significant proportion of human suffering and economic cost [22], [32]. The National Institute for Occupational Safety and Health (NIOSH) has recognized the growing problem of work-related back injuries and published the Work Practices Guide for Manual Lifting [114]. The practice guide contains a summary of the lifting-related literature before 1981, including analytical procedures, a lifting equation for calculating a recommended weight, etc.

Subsequently, this manual lifting tool has been revised to adapt information to the several aspects of manual lifting. The development of the revised NIOSH lifting equation is provided in a separate journal article entitled: *Revised NIOSH Equation for the Design and Evaluation of Manual Lifting Tasks* [157]. The new equation helps to evaluate symmetrical and asymmetrical lifting tasks, including lifts with less than optimal couplings between the object and the worker's hands.

In order to analyse the jobs, the NIOSH lifting analysis has been developed into an integrated program by researchers and software companies in the area of digital manufacturing. Most of those applications provide insufficient support for collaborative working between multiple parties and different locations. In order to meet the requirement of supporting collaborative work over the Internet, a Web-based software tool for NIOSH lifting task has been developed in this work (see Figure 94). This tool is a part of a Web-based prototype for the layout design of workplaces.

The revised lifting equation will evaluate a variety of two-handed manual lifting tasks. The Recommended Weight Limit (RWL) is the principal product of the revised NIOSH lifting equation. The RWL is defined for a specific set of task conditions as the weight of the load that nearly all healthy workers could perform over a substantial period of time without an increased risk of developing lifting-related LBP. Furthermore, the Lifting Index (LI) can also be determined. It provides a relative estimate of the level of physical stress associated with a particular manual lifting task.

In addition to the NIOSH lifting analysis, this prototype software also provides another manual lifting analysis according to Washington Administrative Code (WAC) No. 296-

62-05174 by the Washington Industrial Safety and Health Act (WISHA). This organisation holds a simple way of how to analyse lifting operations.

NIOSH - Microsoft Internet Explorer

FAPS

Heben und Tragen von Lasten nach NIOSH

Hilfe

Arbeitsplatz:

Info:

Bearbeiter:

Datum:

1. Messen und Datenerfassen

Last: Gewicht (kg)		Handlage (cm)						Hubhöhe (cm)		Auslenkungs-Winkel (°)		Hubzeit/man		Arbeitsdauer		Handhabung	
L(Avg.)	L(Max.)	Anfang	Ziel	H ₁	V ₁	H ₂	V ₂	D	A ₁	A ₂	F	LD	C				
13.5	13.5	25	55	50	125	70	0	0	0	0	3	0.75	massig				

Reset

2. Berechnung der empfohlenen Grenzlast und Lifting Index

RWL	=	LC	x	HM	x	VM	x	DM	x	AM	x	FM	x	CM	=	RWL (Kg)	LI
Anfang		23	x	1	x	0.34	x	0.63426	x	1	x	0.96	x	0.95	=	15.982662	0.3446
Ziel		23	x	0.5	x	0.95	x	0.63426	x	1	x	0.96	x	1	=	7.6866257	1.7747

RWL

empfohlene Grenzlast = RWL

Lifting Index (LI) = Lastgewicht/RWL

Figure 94: Analysis of manual lifting according to revised NIOSH equation

8.3.3 Analysis of Work Postures

Poor working postures have been identified as the major causes of musculoskeletal disorders. This type of disorders produces a high number of worker's compensation claims. By analysing working postures, poor postures can be identified and improvements evaluated. Thus, analysis should contribute to the reduction of the number and severity of these disorders [16].

Several systems for analysis of posture have been developed and even computerised to speed up calculations [67], [81], [87], [154]. In a similar way, based on the OWAS (Ovako Working Posture Analysing System) method, a Web-based tool for analysing the work postures has been developed in this work. This analysing tool is integral part of the Web-based prototype for the layout design of workplaces. The OWAS method [146], which was developed in the Finnish steel industry and later enhanced by the Finnish Centre for Occupational Safety, defines postures according to the position of various body parts: back, arms, legs and neck, and the effort being exerted. The posture information is sampled over a representative period for the work of interest. The data can be analysed in two ways: either according to the combined effect of the position of the body

parts, or the time spent in a particular position for each body part. The effect on the musculoskeletal system is graded on a four-point “action category” scale.

The Web-based tool package is an analysis program that examines the data according to OWAS determination of the action categories. Embedded and presented in a Web page, the program automatically prompts the observer for data in an interactive way. There, the OWAS number codes need to be entered. They reflect the position of various body parts: back, arms, legs, and the effort being exerted. As the observer enters the codes, the selection is highlighted providing feedback and allowing correction. This OWAS posture analysis tool acts as an ergonomic checklist for the developed software prototype. The human postures, which are the result of a working task in a virtually designed workplace that use this tool, can be evaluated. Subsequently, it assigns a score to evaluate the posture that indicates the urgency of taking corrective measures to reduce the posture’s potential to expose workers to injury.

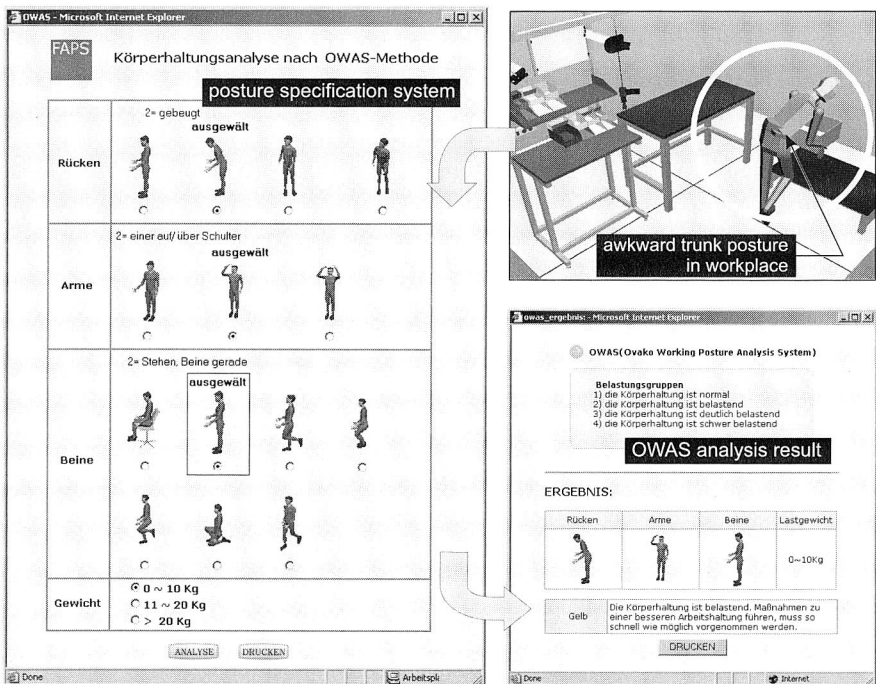


Figure 95: Web-based tool to analyse work postures (according to OWAS)

Figure 95 depicts the use of this tool for the Web-based prototype, which is needed in the layout design of manual workplaces. As a first step, the potential risk for an awkward human posture in the workplaces should be identified. Using this Web tool, the

observed postures of the human bodies as well as the effort being exerted can be translated into an OWAS code (e.g. code 2-2-2-1 for an example in Figure 92). Subsequently, the current work posture according to the OWAS system is evaluated. The result is one of the four following categories: 1) normal, with no preventive action required; 2) slightly harmful, indicating that changes should be made in the near future; 3) distinctly harmful, with changes needed as soon as possible; and 4) extremely harmful, with immediate changes needed. These categories will be indicated in the program by using several colours (green, yellow, orange and red respectively).

8.4 Web-based Software Tool for Time Measurement

In order to maintain productivity and a competitive process, companies must continually rationalise their operations to achieve shorter delivery times, lower operation costs, optimum resources utilisation and the flow of materials. At the same time, the total automation approach that was rather popular in the past is being replaced to an increasing degree by partially automated, hybrid production systems, which are more flexible.

In the face of global competition and the demand for job security, more attention should be paid to the use of personnel in the workplace. The planning often results in badly planned workplaces in which the full output is never reached and the employees are not happy. For that reason, planning tools with analysis capabilities are required to effectively design the manual and partially automated workplaces. This includes predetermined time systems for manual as well as partially automated operations, which are often found in the assembly systems.

8.4.1 A Predetermined Time Standard System

A predetermined time standard system is a collection of ready-made time values for basic motion elements without any need for stopwatch timing. Experienced time analysts who agreed on certain basic factors, concepts and constraints underlying their system originally developed predetermined systems. A traditionally predetermined time system evaluates the manual works by analysing and subdividing tasks into elemental motions, and then assigning preset standard times for these elements as well as summing them into standard time. Method Time Measurement (MTM), the Work Factor System (WFS) and Dimensional Motion Times (DMT) are some examples for predetermined time systems [73].

8.4.2 Method Time Measurement (MTM)

The MTM is a procedure to improve methods and to establish time standards by recognising, classifying and describing the motions used to perform given operations and then assigning pre-determined standards to these motions. The procedure was first developed in the 1940's but has more than kept up with the modern world. The concept of a motion study in which an analyst equipped with a stopwatch and a clipboard stands behind a factory worker is far from reality. Today, an industrial engineer, assisted by the

latest computer systems available like the software TiCon® [71], skilfully applies the methodology; indeed the system cannot be integrated in a Web based application.

To meet the varying needs of business and industry, MTM provides a dynamic and growing family of systems. MTM is a family of predetermined time systems, which has evolved through a progressive programme of research and development directed to lead to practical solutions for application requirements. The MTM systems available in industrial engineering practice are MTM-1, MTM-2, MTM-UAS (Universal Analysing System), and MEK (*MTM für Einzel- und Kleinserienfertigung*) [27].

The screenshot shows a web-based interface for time measurement using the MTM-UAS method. At the top, there are input fields for 'Arbeitsplatz:' (Getriebemontage) and 'Info:' (Datum 14.10.2004/Bearbeiter A. Sutorio). A button labeled 'MTM-UAS Data card' is visible. Below these are buttons for 'MTM-UAS-DATENKARTE', 'DRUCKEN', and 'HILFE'. The main section is titled 'Zeitanalyse nach MTM-UAS' and contains a table with 10 rows of activities. The table columns are: Nr., Vorgänge, Kode, TMU, A, H, Gesamt, Zeit, and Beschreibung. Below the table, there are fields for 'Gesamtzeit:' (30.42 sekunde, labeled 'calculated time'), 'Zuschlag auf MTM-Zeiten [%] : 12', 'Erholzeitzuschlag [%] : 5', 'Verteilzeit [%] : 5', and 'Vorgabezeit:' (37.11 sekunde, labeled 'standard time'). An image of a worker at a workstation is shown on the right side of the interface.

Nr.	Vorgänge	Kode	TMU	A	H	Gesamt	Zeit	Beschreibung
1	Gehen 3 m zum Behälter u. zurück zum Tisch	KA	25	3	2	150	5.40	näher an Tisch
2	Bücken und aufrichten	KB	60	1	1	60	2.16	
3	Gehäuse in Vorrichtung setzen	AJ1	40	1	1	40	1.44	
4	Gehäuse in Vorrichtung festspannen mit Hebel	BB1	30	1	1	30	1.08	
5	Deckel auflegen	AB2	45	1	1	45	1.62	
6	Deckel auf Gewindebohrungen ausrichten	FB1	20	1	1	20	0.72	
7	Unterlegscheibe auf Schraube stecken	AE2	55	4	1	220	7.92	integrier. Scheibe
8	Schraube mit U-Scheibe in Gewindebohrung	FC1	30	4	1	120	4.32	
9	Schraube abdrehen. 4 Turnusse	ZB1	10	4	4	160	5.76	
10								

Figure 96: A part of the @WebPlan modul, a Web-based software tool for time measurement according to the MTM-UAS method

The MTM-1 is the original system. Here, the motion patterns are analysed in great detail and precision. The MTM-1 is particularly suited to short cycle work. A second level of the MTM system is named MTM-2. Data flow and the speed of the application are faster than the MTM-1, but a small degree of accuracy is lost. Another method like MTM-UAS is a second generation of synthesised data based on MTM-1. It was constructed by means of a statistical analysis of MTM-1 motion patterns. MTM-UAS is one of the most popular systems and is up to 8-times faster than MTM-1. The precision and application speed of MTM-UAS make it best suited for the use in batch production with long cycle times (4 minutes or longer).

Most of the MTM software available on today's market merely provides insufficient support for collaborative working between multiple parties and different locations. This Web-based software tool for time measurement developed within this thesis offers the possibility to access the same software platform over the Internet. This tool is a part of the @WebPlan module for layout design of manual workplaces, which add the tool's capabilities for analysing the assembly operations based on the MTM method. Figure 96 depicts a screen shot of the software tool for time measurement according to the MTM-UAS method.

In order to guide the user to choose a suitable MTM-UAS code for each motion sequence, an MTM-UAS data card (Figure 97) is available by clicking the "MTM-UAS data card" button in the application. This method consists of seven basic sequences for manual activities, and each of them has influencing variables. For instance, in case of *pick up* basic sequence, the influencing variables are categorised into light, difficult or with handful an object to be picked up. The last parameter of this method reflects the distance zones. The distance zone 1 is for the motion length ≤ 20 cm, the distance zone 2 for motion length $> 20, \leq 50$ cm and the distance zone 3 for motion length > 50 and ≤ 80 cm.

Aufnehmen und Plazieren		Hilfsmittel handhaben (Aufnehmen und plazieren und plazieren)			
<= 1 Kg	Leicht	Ungefähr	AA1	Ungefähr	HA1
		Lose	AB1	Lose	HB1
		Eng	AC1	Eng	HC1
	Schwierig	Ungefähr	AD1	Betätigen	
		Lose	AE1	Eine einfache Betätigung	EA1
		Eng	AF1	Zusammengesetzte Betätigung	EB1
	Handvoll	Ungefähr	AG1	Bewegungszyklen	
		Ungefähr	AH1	Eine Bewegung	ZA1
		Lose	AJ1	Bewegungsfolge	ZB1
> 1 Kg und <= 8 Kg	Eng	AK1	Umsetzen und eine Bewegung	ZC1	
	Ungefähr	AL1	Festmachen und Lösen	ZD1	
	Lose	AM1	Körperbewegungen		
> 8 Kg und <= 22 Kg	Eng	AN1	Gehen/ 1m	KA	
	Plazieren		Beugen, Bücken, Knien u. Auf.	KB	
	Ungefähr	PA1	Setzen und Aufstehen	KC	
Lose	PB1	Prozesszeit			
	Eng	PC1	Beeinflussbare Prozesszeit	PTB	
	Visuelle Kontrolle	VA	Unbeeinflussbare Prozesszeit	PTU	

Figure 97: MTM-UAS data card

Using the list available in the software module for time measurement, the user can describe assembly operations and enter codes respectively. The new row from the list is automatically added, if the previous one has already been filled in. In addition, the required time from a set of assembly operations is calculated automatically. Subsequently, the standard time for an assembly task is composed according to REFA standard [129]. It is calculated according to the following equation:

$$T_{\text{standard}} = T_{\text{calculated time}} + T_{\text{allowance}}$$

The calculated time is the result of cumulative calculation according to the MTM method. This time is also considered to be a basic time. Furthermore, time allowances include:

- Allowance on MTM times (%),
- Recovery time allowance (%),
- Personal and technical delay time allowance (%).

The time allowances are expressed in percent, and each allowance refers to the calculated time (basic time).

8.5 Implementation of the Prototype

The prototype has some features to be implemented. It has a *3D View* window as a virtual design space, in which the user is able to allocate objects within this space and to transform the position of objects by means of moving or turning functions. Using scaling operations we can resize the shape of the 3D object in order to examine different dimensions of the allocated objects. In addition, object-to-object collision detection and measuring of a metric distance between two arbitrary points are further available features in this prototype. The list of assigned objects can be created and the design results can be saved, opened, uploaded or downloaded in a Web-based client-server interaction. Particularly for the 3D objects library, this prototype provides various human models with the 5th, 50th, and 95th percentile for both male and female. A human model in VRML enables the user to manipulate its virtual postures according to the assembly task. The objects library also provides the Anthropos human model, which consists of the male and female 5th, 50th, and 95th percentile with sitting and standing posture. Furthermore, the Anthropos models are available with some reach ranges (ideal, physiologically maximum, geometric maximum, and with upper body movement reach range). The important features in this prototype, which differentiate it from the layout-planning prototype, are the time measurement system and ergonomic checklists. These features are incorporated into the prototype software in order to design and evaluate workplace layouts with both ergonomic (human factors) and economic (assembly time according to MTM time analysis) considerations. This results in a properly designed workplace, which will increase the worker's productivity, morale, and product quality. The software prototype has been conceived to deal with economic and ergonomic considerations. It allows designing human-workplace systems easily and distributing them among parties.

There are some issues related to human-workplace system modelling and analysis of working posture for manual assembly workplace layout design and planning. The workplace can affect the working posture of the human workers in certain ways. The location of the bins used to store the components, as well as parts, supplies and tools influences the ranges undergone by the wrist and elbow joints. A bin placed in a location requiring

an excessive reach would result in the straining of the wrist and elbow joints. The second factor is the table configuration of the workplace. Improper table height and depth would result in the operator adopting awkward working postures to perform the task at hand. The other factors are locations or positions of the seat and the assembly centre, respectively, which may also influence the motion ranges of the wrist and elbow joints and the working posture. Similarly, the improper seat and assembly centre locations would also result in the operator adopting awkward working postures to perform the task at hand.

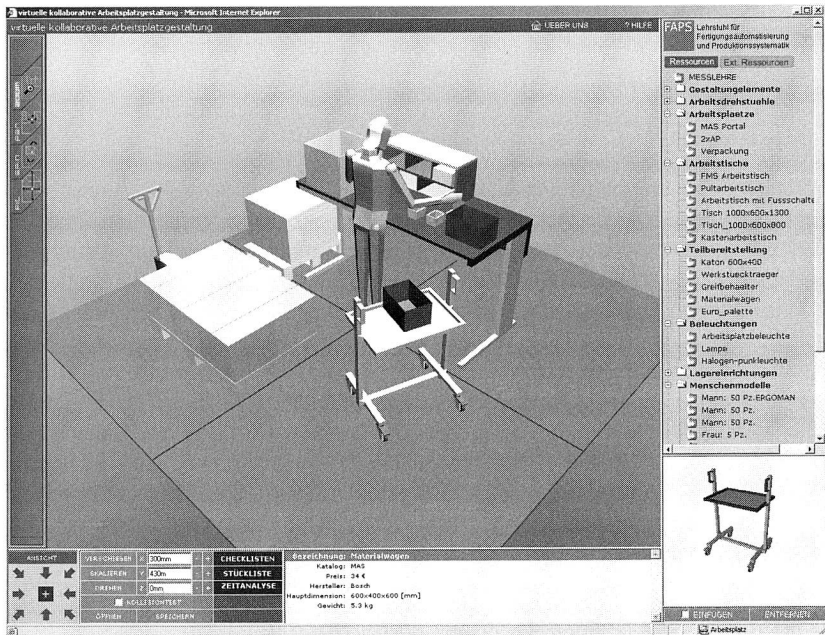


Figure 98: A Web-based tool for layout design of a manual assembly workplace (packaging workplace)

The human models, which consist of male and female 5th, 50th, and 95th percentile with sitting and standing posture, can be used to accommodate the workplace dimensioning. The work position can be checked regarding the height relative to the heart. Thus, using a variety of reach ranges, which are enclosed in the human model, we can optimise location of bins, parts, tools and supplies. Reachability of the object and human posture can also be determined due to an assembly task. Figure 98 depicts the implementation of the software prototype to the layout design of a manual packaging workplace. The online virtual environment with 3D capabilities in this software prototype allows the participant to speed up the exchange of ideas, reduce misunderstandings and facilitates

problem solving from different locations. As a result the collaborative design process is significantly improved.

9 Conclusions

The increasing complexity in the production planning area due to shortened product life cycle in combination with market turbulences challenges engineers to seek proper solutions. Planning and design of production systems using a Virtual Manufacturing approach by means of digital models to represent real manufacturing systems provide an effective solution to cope with those challenges. Modelling and simulation of complex manufacturing systems on the computer enable engineers to develop, evaluate and refine various alternatives, and consequently lead to accelerate processes in obtaining planning results. In addition, the emerging of new technologies enabling cooperation in global networks as well as the trend towards globalisation and virtualisation of processes also stimulate new methods and tools. These enable multiple parties in different locations to collaborate in a common, virtual simulation environment. The trends and challenges, which have been portrayed previously, have been discussed in this dissertation. A special focus of interest was to develop solution approaches for the planning of assembly systems under consideration of the aspects mentioned above.

In connection with a significant trend towards modular assembly systems in order to adjust to an increasing assembly flexibility, the work focuses on the development of such an integrated approach by means of using a variety of templates as assistance tools for modelling various types of components of modular assembly systems. In the templates, several parameter values of every modular component can be stored and then a corresponding 3D model is generated automatically. In the same manner, the simulation types as well as further information, e.g. price or weight of the component can be assigned to the computer-generated 3D model. In addition to the generation of digital models, the digital components developed have been assigned to selected layout configurations by using the same technique. Moreover, a given layout configuration can be digitally reconfigured to another configuration, followed by updating its parameters. Using the modelling approach, a model for material flow simulation can be generated from a 3D modular assembly line. Using a material flow simulator can run this model. Thus, the analysis of the assembly systems can be performed from a logistical point of view. The advantages of the modelling approach for modular assembly systems include modelling process flexibility, a significant improvement in the development of structured and efficient techniques for 3D modelling of modular system components as well as an acceleration of the planning tasks and the layout structure reconfiguration.

A substantial aspect of the design of assembly systems is the improvement of workplace layouts along with activities regarding manual tasks. Hence, further consideration in the present work is given to the identification of the improvement potentials in ergonomic workplace designs by using a Virtual Manufacturing approach, particularly by human simulation. Consequently, results concerning ergonomic and efficient working parameters such as body postures, forces and moments encountered at joints while performing different tasks and cycle time along with corresponding MTM-codes have

been obtained by means of a case study. Thus, an improved workplace design considering ergonomic factors from various design alternatives can be ensured.

Increasing globalisation of markets and virtualisation in design processes has forced most companies to reconsider their flexibility and adaptability requirements. There is an increasing number of internationally oriented companies; consequently their employees work in a geographically distributed environment. This change opens up opportunities for developing an adequate method for production planning, which enables the integration of dispersed planning teams across multiple locations. Therefore, a further focus of this dissertation was to develop a virtual collaborative environment for planning of assembly systems. The new planning tool, called @WebPlan, is based on modern internet technologies and gives remote users a multiple, simultaneous and distributed access to the project data including 3D models in a Web browser.

The distributed planning environment utilises a Web-based client-server architecture. In this architecture, the client of the system is the Microsoft Internet Explorer (as Web browser) and the Apache HTTP Server has been implemented as server software behind the Web. Thus, multiple planning spaces can be set by a server and the planning services can be delivered on-demand to the distributed participants. The 3D objects exist as the VRML 3D objects and they are imported from several common CAD systems. As an emerging industry-standard and a platform-independent file format for 3D graphics, VRML offers a number of advantages like a low requirement of additional utilities and highly interactive 3D models with complex behaviour. @WebPlan is available with a number of structured 3D objects such as digital models from machines, equipments or other facilities. An XML-based objects library system was deployed to organise a large number of these objects along with their information and graphics. In addition to the objects library on the server, the system also possesses possibilities to involve other 3D objects as external libraries from remote locations outside the server. Thus, resources from customers, partners or suppliers can be integrated into the system and used for planning processes.

The @WebPlan planning tool consists of several modules. A Web-based prototype for layout planning of assembly lines is the first module. This prototype allows distributed project planners to arrange planning objects in a shared model and thus several alternatives can be discussed immediately with other participants. A stepwise method, from block to detailed layout planning, is also considered in the design of the prototype. Another module is a prototype for layout design of workplaces over the Internet. Using this prototype, several distributed design spaces can be activated for workplace layout designs. Moreover, ergonomic checklists and time measurement according to the MTM-method are available as additional online tools for workplace design.

A relevant contribution to the efficient planning process of assembly systems has been achieved within the scope of the present work. This approach shows the potential of a Web-based collaborative virtual environment for planning processes regarding the reduction of planning times and costs. The online environment with its built-in 3D

capabilities allows parties in different locations to speed up the exchange of ideas, reduce misunderstandings and facilitate problem solving and as a result significantly improve the collaborative design process. Compared to other planning solutions in this area, the planning processes using this approach can be delivered on-demand at any time and place. This solution also provides both synchronous and asynchronous planning environments for geographically dispersed users. Further potential development may comprise an enhancement of @WebPlan compatibility for all operating systems and browsers by means of using the Java programming language. In addition, another planning option can be supplemented into the existing one, so that all participating members are informed in real time about changes of the model and at the same time other collaborating users work on an updated version.

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Abbreviations

3D	three-dimensional	MPEG	Moving Picture Experts Group
API	Application Programming Interface	MTM	Method Time Measurement
ASCII	American Standard Code for Information Interchange	OLE	Object Linking and Embedding
BIFS	Binary Format for Scenes	OSI	Open System Interconnection
B-rep	Boundary Representation	REFA	Reichsausschluss für Arbeitstudien
CAD	Computer Aided Design	SDK	Software Development Kit
CAE	Computer Aided Engineering	SGML	Standard Generalized Markup Language
COM	Component Object Model	TCP	Transfer Control Protocol
CSG	Constructive Solid Geometry	URL	Uniform Resource Locator
CSS	Cascading Style Sheet	VDI	Verein Deutscher Ingenieure
DIN	Deutsches Institut für Normung	VR	Virtual Reality
DMU	Digital Mock-up	VRML	Virtual Reality Modelling Language
DOM	Document Object Model	W3C	World Wide Web Consortium
DSL	Digital Subscriber Line	Web3D	3D graphics on the Web
ECMA	European Computer Manufacturers Association	WMSD	Work-related Musculoskeletal Disorder
HSF	Hoops Stream File	WWW	World Wide Web
HTML	Hypertext Markup Language	X3D	Extendable 3D
HTTP	Hypertext Transfer Protocol	XHTML	Extendable Hypertext Markup Language
IE	Microsoft Internet Explorer	XML	Extendable Modelling Language
IP	Internet Protocol	CSCW	Computer Support Collaborative Work
ISDN	Integrated Service Digital Network		
ISO	International Standard Organisation		

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