

# TRIVERA: AN EFFICIENT TOOL FOR COST INTEGRATION INTO 4D MODELS

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**Abstract:** State-of-the-art three-dimensional (3D) software allow for information exchange with other software used within the AEC industry. In advanced applications construction schedule has been successfully integrated into 3D projects, and the resulting 4D models provide an innovative decision making tool that can facilitate the construction of large scale projects. Though 4D CAD applications in building design allow for the visualization of the construction sequence, are not designed to support the time sequenced display of cost related information. Current methods of construction integrated design do allow linking cost to a 3D software, but such applications are mostly data oriented, do not support information visualization, or are hard to utilize with commercially available software. An efficient and user friendly method for integrating cost to 4D CAD models for construction has been developed. A key feature of the method is a software application, TriVera, that facilitates the integration process. TriVera is designed to link the cost of materials reports generated from the 3D software, with the cost of resources reports generated from the scheduling software, and allows for the display of cost at the same time sequence as the construction schedule animation.

**Keywords:** Cost Integration, Construction visualization, Cost Visualization, 4D CAD

## 1. INTRODUCTION

The number of contractors that use 3D Computer Aided Modeling in order to better visualize complicated design is constantly increasing. However the capabilities of 3D software are only marginally exploited during construction. Indeed, data that could be extracted from the model, or data that is already included in the software, is not used for developing or updating cost estimates, and hence data has to be re-entered in a different format wasting time and money, or is corrupted resulting to loss of vital information.

To respond to the need for efficient planning tools, a number of approaches to automate the planning process in related domains have been proposed [1][2], while the more general notion that ‘Computer Aided Design (CAD) drawings of the site and other supportive non-graphical information should be tightly integrated to fully describe planning situations in an interactive environment’, has been expressed over a decade ago [3]. In state of the art project management processes, contractors can choose one construction plan over another based on construction process visualization (4D CAD). Three dimensional computer aided design is currently not only used as a base for the 4D CAD but also as an effective platform for the integration of more project parameters through the concept of interoperability and the application of classes. Construction visualization 4D CAD models, provide invaluable information for the construction process, however they do not display information on the effect of alternative construction schedules on cash flows. Reversing the problem, although contractors have access to

cost estimates, their usefulness is rather limited since they do not reflect or highlight the specific costs related to constructability problems.

Within the general requirement for the development of methods for the visualization of building construction related information, this paper focuses on the emerging need for displaying cash flow information along with the construction sequence visualization. Before presenting a new software application that addresses this problem, basic concepts and state of the software capabilities that made this application possible are discussed.

## 2. COST ESTIMATING IN CONSTRUCTION

### 2.1 Industry Foundation Classes (IFC) and Cost Estimating Software

The main task of the International Alliance for Interoperability (IAI), formed in 1994, was to enable information sharing throughout the project lifecycle and across all disciplines and technical applications in the building industry [4]. Thus several classes of elements, named Industry Foundation Classes (IFC), defined as international standards for the building model data exchanging, have been developed and organized hierarchically by IAI. As IFC is non-proprietary and available globally to AEC/FM software developers and enables communication among AEC/FM software applications, gradually renders interoperability a reality for AEC firms, building owners and authorities that use IFC-compliant software [5].

The efforts of IAI are focusing on being able to share the data, enter it once and transfer it seamlessly between platforms and among applications. According to this

perspective each discipline contributes and withdraws information from the core model, which reduces errors and omissions and obviously saves time and money [4].

For the purpose of this research a very important aspect of the IFC is the fact that they support the generation of cost estimates and assist estimators with the maintenance of cost estimates throughout the project life cycle changing the expectations of engineers from the existing cost estimating software.

Yet, despite the broad use of related software, not all companies use Construction Cost Estimating Software to prepare their bids, possibly because the use of standard cost database does not increase contractor's competitiveness. Hence the use a cost database developed outside the company, in order to prepare a cost estimate, make spreadsheet software (e.g. Microsoft Excel) is still the preferred one by some construction companies when it comes to preparing cost estimates. Being aware of this fact, and in order to increase their market-share, many construction cost estimating software companies today have incorporated the spreadsheet functionality in their software. Spreadsheet interface, allowance for modification of the cost database, Open Database Connectivity (ODBC) with spreadsheet software, or even Construction Cost Estimating add-ins for spreadsheet software are very common in today's Construction Cost Estimating Software Systems (CCESS). In addition, some construction cost estimating software companies have already started offering their software on the Internet. Therefore the cost database is no more stored on the cost estimators computer, but on a server.

Current estimating software helps estimators take off quantities automatically by taking advantage of the IFC concept and establishing an electronic link between a component in a 3D-product model and a cost item in a cost estimating database. On average, each item in a cost estimate is created seven times throughout the life of a project. Consequently, it is critical that IFC support the generation of cost estimates and also assist estimators by maintaining the cost estimates throughout the project life cycle [4].

In state of the art software, as in "Timberline" environment [6] a designer who uses IFC-compliant software, such as a CAD program, can save designs in IFC format, then imports the IFC data, and the software. Estimator generates a takeoff and an estimate, and writes the cost estimate back to the IFC file. Should the design change, a new estimate can be generated in minutes. However, when the users need assistance in maintaining cost estimates throughout the project, the existing estimating software lack the necessary functionality. This problem is even more acute in the case of design changes. The reason is that construction costs are not only affected by material quantities but also by component properties (e.g. size and shape), and product features (e.g. repetition and openings) [7].

Except from the direct material, cost deriving from a quantity take off, a cost estimate generally includes all costs related to site preparation, project financing costs,

temporary facilities, project definition costs, insurance, acquisition/rent of land and property, taxes, project management, engineering costs, direct construction labor costs, quality assurance costs, start-up costs, escalation, contingency, operations and maintenance. Only direct material and labor cost are considered in the scope of this research.

## 2.2 Computer Integrated Construction (CIC)

The goal of CIC technology is to fully integrate the project information by linking the various "knowledge based operations" that occur on a project such as stand-alone CAD, spreadsheet, database and scheduling software packages using Visual Basic 'for Applications (VBA). In 2001 a 3D CIC prototype system was developed that demonstrated the potential use of CIC for improvement of the constructability analysis and the construction management process of concrete projects. "The prototype is capable of generating three-dimensional intelligent construction objects, generating quantity takeoff and integrating with schedule". [8].

Among the multiple benefits from the use of CIC technology, it needs to be mentioned that since the estimated quantities are linked electronically to the schedule, the construction work is conducted easier and faster especially in the case when the project success is cost driven. Another benefit is related to the fact that the designers and builders extract electronic information from the data bases of the suppliers where prices and availability are provided. This is possible through the use of a common symbol library, such as the IFC. Finally there are many advantages related to remote location transmits, communication improvements, having up-to-date design, schedule and cost information [9]. Unfortunately, the CIC technology, albeit all its other benefits to the construction management process and practice and the efforts of the International Alliance for Interoperability that holds the leading edge in collaborative efforts that allow data transfer between building model software and analytic applications, including cost estimating, and construction scheduling, does not acknowledge the existing need of visualization within the AEC industry.

## 3. CONSTRUCTION SEQUENCE VISUALIZATION (4D CAD)

Working with AEC design software requires interoperability frameworks, a part of which relates to cross-file interchange of model geometry. Such software developments though do not typically include cost and schedule data in their interoperability framework, despite the fact that the International Alliance for Interoperability, maintains that "The potential savings in construction cost alone are expected to range from 15% to 40%, with parallel reductions in construction schedules" [10]. A major key to the success of these efforts is establishing common software protocols.

Integrated design is supported from many research teams. The effort is summarized on taking the concept of 3D computer modeling on an almost infinite number of dimensions, in order to handle whole-life construction and asset management issues in the design of modern buildings [11]. Ultimately the idea of integrated design has been transferred into construction.

Visual 4D models combine 3D CAD models with construction activities to display the progression of construction over time, sometimes dramatically improving the quality of construction plans and schedules. Feedback from construction to the design team, resulting from 4D model reviews, can often lead to a more readily constructible, operable and maintainable project. Construction Sequence Visualization or Schedule Simulations allow for visualization of a schedule by integrating 3D engineering data with a construction schedule. Practically a Schedule Simulation relates graphic model objects and schedule activity objects.

There are many state-of-the-art 4D software commercially available for the construction industry such as the Bentley Navigator and PM Vision. With the use of 4D CAD, project managers can: create and update realistic schedules, rapidly re-sequence activities when necessary while reducing the risk of running out of space. Changes in the schedule are automatically updated by updating the design and schedule links.

4D simulation and virtual reality techniques as part of a Detailed Planning Module can be used in order to allow site supervisors to visualize, rehearse, and develop construction plans [12,13]. Studies have shown that 4-D CAD have a positive impact on the project time schedule, cost, productivity, and quality [14].

Unfortunately, the capability and functionality of these applications are limited when required to fully assist generation of detailed execution plans. An interface that connects the 4D module to the database is also essential to receive feedback and additional data from the supervisors [15]. Consequently, this fact raises many questions such as what should be the skills of the superintendents and foremen to operate these databases, how easy it will be to find people with these skills and in case the question comes to train them, what will be the return for this.

## 4. COST INTEGRATION AND VISUALIZATION

### 4.1 Scheduling with Cost Integration Capabilities

Scheduling software that is broadly used in construction industry to facilitate effective management of projects, practically comprises part of the project controls defined as the process of planning, directing, and controlling the project from the start of construction through its completion. One of the essential concerns is that the information developed for the estimate should be presented in a way that can be easily used during the actual construction project [16].

In construction scheduling, material deliveries, equipment and people are all managed through the schedule.

In “traditional” project management, a CPM schedule is developed that simply records the daily activities and helps the project manager graphically record progress and anticipate future problems [9]. Moreover recently developed scheduling software are often used for cost estimating as they allow for development of estimate information that can be easily used during the actual construction project. To generate cost estimates for labor costs the estimator/scheduler needs to have a completed quantity take-off, a list of crews and their activities, a list of crafts included in the crews, the wage rates for all of the crafts and the productivity rate for each crew [16].

Scheduling software focus basically on improving the resource management, cutting costs and making employee scheduling, room scheduling and shared equipment scheduling easy for everyone for companies of all sizes. Some of the available features include: simplicity of use, minimal server requirements, no need of additional software, web and browser based, remote access, day / week / month views for schedules, customizable time display, resource utilization and costing reports

The effort of this research focuses on the development of an application that integrates material take-off with labor cost and takes advantage of the precision in quantity calculation resulting from detailed 3D models. The effort extends to the integration of the generated cash-flows within a 4D CAD model - that animates the construction sequence - by keeping the same timeline of the 4D CAD model.

### 4.2. 4D CAD Model Development

4D CAD is not a standard procedure and has been used only on a limited number of large scale building, infrastructure and general civil projects. Large scale Projects in the planning and construction of which 4D CAD modeling processes have been used include the San Mateo County Health Facility, the Experience Music Project at Seattle, the Roof for Haas School of Business at UC Berkeley [17] as well as the Dallas High Five infrastructure project [18].

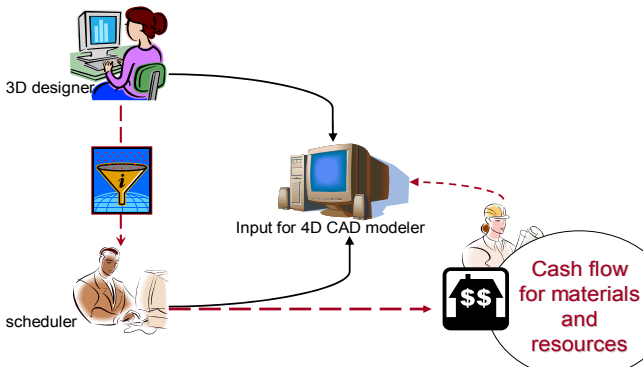
In order to generate a 4D model, its 3D design needs to be combined with information developed from scheduling. Since schedulers in traditional project management are not expected to develop the scheduling activities, to accommodate the names and the ID's of the 3D model objects, the information provided for the development of the 4D model cannot be used without being first analyzed and appropriately modified.

Essentially, during the development of the 3D model, data is entered on materials, while simultaneously or later, the scheduler creates his model based on 2D plans, or the work breakdown structure (WBS) provided by the contractor. Therefore, when the information for the generation of the 4D model is finally delivered, it often has to be re-entered or adjusted. Apparently even when a 4D CAD construction schedule simulation is being employed, the information provided by the scheduler cannot be fully

exploited because the resource loading he has already developed is not being used.

**4.3 TriVera: Basic Features & Processes**

The proposed method (**Error! Reference source not found.**) reroutes the flow of information and benefits from this procedure by handling more data. Specifically the scheduler, instead of working independently for the development of the scheduling model, will first filter the information included in the 3D model, and then provide all necessary data for the development of the cash flow for materials and resources. The next step will be to integrate the cash flows into the 4D model and to visualize the changes in the cash flow while running the 4D model. In more detail the steps that are proposed are as follows:



**Figure 1: Standard vs. Proposed process for 4D modeling**

*STEP 1: Material take-off*

This step leads to the generation of a bill of materials. In order to perform the quantity take-off, the MicroStation TriForma has been used since: (a) allows for easy quantity take-off and (b) is compatible with commercially available 4D construction visualization software. Specifically, the selected software is a solid modeler and can generate quantification reports (material quantities, schedules, specifications, and cost estimates) from an integrated 3D project model. TriForma maintains the information link between the model and all related documents and consequently, once a change is made on the 3D model, all the deriving documents update automatically.

Using TriForma’s reporting effectiveness, it is possible to count or quantify every building/structure related information, such as the total area of brick walls, the total number and type of columns etc. The most important outcome from this step is the detailed report (in xls format) that contains all the quantities generated by each element in the 3D model (**Error! Reference source not found.**). The generated report in the Microsoft Excel file is dynamically linked to the model and lists the quantities of the materials

sorted first according to the component and then according to their IDs (e.g. the amount of cubic yards for every column). It can also list the unit price of the materials and finally the total cost per component.

Component number	ID	Quantity	Unit price
Component 1	1	q1	p1
	2	q2	p1
		Total for component 1	Total for component 1
Component 2	3	q3	p2
	4	q4	p2
		Total for component 2	Total for component 2

**Table 1: Report generated from MicroStation TriForma**

*STEP 2: Resource Loading*

At the completion of this step the bill of labor costs is generated. The commercially available and widely used Primavera Project Planner is the selected software for this step.

In this step the scheduler Retrieve the IDs of the elements from TriForma, then add scheduling activities for all desired objects of the 3D model. Subsequently he adds resources and their unit costs for each scheduling activity. The detailed report (csv) contains all labor and engineering costs for each activity/element of the 3D mode, and appears in the format shown in **Error! Reference source not found.**:

Resources	ID	Quantity	Unit price
Labor	1	q1	p1
	2	q2	p1
Field Engineer	1	q3	p2

**Table 2: Report generated from Primavera Project Planner**

*STEP 3: Generation of 4D model*

For the generation of the 4D model, Bentley’s Navigator was chosen as a state-of-the-art software that encompasses the concept of classes and is compatible with both Bentley’s TriForma and Primavera Project Planner.

The schedule objects, as defined within Primavera Project Planner, are linked to the graphic objects that were previously created with Bentley’s TriForma.

When a Schedule Simulation is being replayed, the Navigator obtains graphic or geometric data from the graphic object in the model. JSpace used by Navigator makes possible this process through the use of JSpace model. and J SPACE classes. More specifically the OLE

links enables the creation of JSpace schedule models by using data that is imported from external schedules.

Before linking the 3D model to the scheduling activities the following tasks must be completed:

- Extract the JSPACE model from Triforma and open it in Navigator
- Insert the activities from P3
- Create the new JSPACE model from P3
- Link the objects of the 3D model to the activities of the P3

Once the graphic objects are linked to the scheduling activities, the 4D model is automatically generated, and in the next step the cash flows will be generated in order to integrate them in the 4D model

#### STEP 4: Generation of cash flow: TriVera

Once the material take-off and the resource loading are complete, the next goal is to generate the cash flow that includes the material and labor costs. The combination of this information since it is deriving from different software is not feasible with the currently available software.

Hence there is a need for the development of a new tool that will allow the merging of the two spreadsheet files and will generate the cash flows. Therefore a commercial software based application that allows for linking the labor costs with the material costs on a predefined timeline has been developed. The conceptual approach and use of this application as part of the process are explained in the following section.

A simple and user friendly application was developed to facilitate the needs of this step of the process as the files generated from MicroStation TriForma and Primavera Project Planner needed to be linked. The application is called TriVera (since it is combining files generated from TriForma and Primavera) and is written in Visual Basic. Basically it is an add-in for Microsoft Excel and can be easily installed.

The conceptual approach, shown in Figure 3, depicts the procedure repeated every time the application is used. First, the unique ID generated within TriForma for every element chosen to display is retrieved from the detailed report. This ID is used by the scheduler to schedule the respective activity. The two files are combined within TriVera to create a new Microsoft Excel file and then generate the cash flow,

The procedure performed by TriVera in order to create this new Microsoft Excel file is the following:

- The application defines the ID of the first scheduled activity listed in the first pre-defined time period (e.g. a week) in the file created from Primavera.
- This ID from the Primavera Excel file is matched with the ID in the TriForma Excel file and the cost of labor and materials is identified, respectively.
- Once the same procedure is repeated and completed for all the IDs listed under the first pre-defined period, the two types of costs are plotted on the cash flow output.
- The same procedure is repeated for every time period reflected on the cash flow.

It is important to note that the cost of material is credited at the beginning of the activity, while the cost of resources shows on the cash flow for the required time to complete the construction activity.

Once the cash flow is generated the next step focuses on its integration in the 4D model.

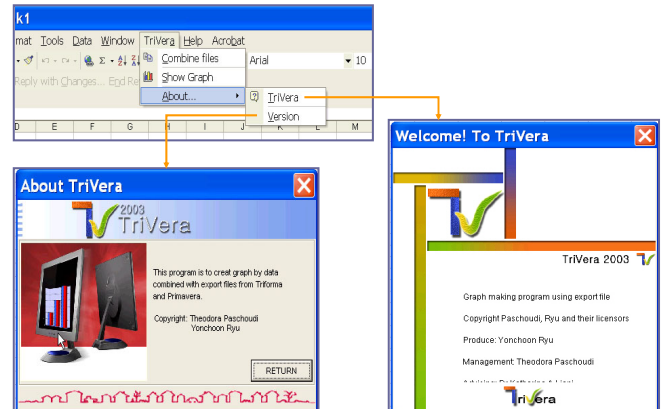


Figure 2: TriVera 's menu interface

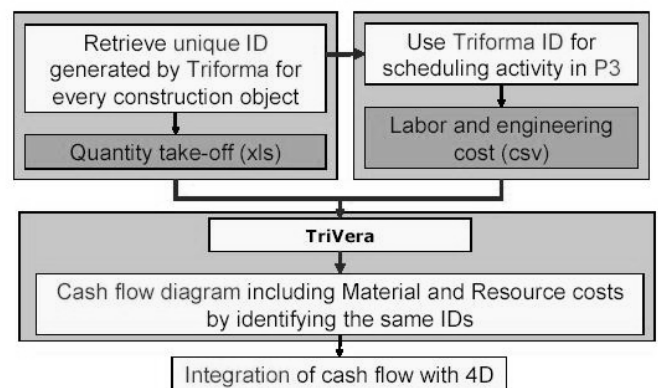


Figure 3: TriVera's conceptual approach

#### STEP 5: Visualization/Decision-making

In this step the animation of the cash flows is generated establishing the integration of cost into the 4D model.

Before using the animation creation software, the user has to generate from TriVera all the necessary cash flows he desires to display simultaneously to the display of the 4D model. Once all the cash flows are generated for regular time frames throughout the progress of the project then Vegas can be used and the next actions to be taken are:

- Define the timeline of the animation of the 4D CAD
- Use the same timeline for the animation of the cash flows

At this point of the research it is not possible to have the animation in the same screen as the 4D CAD display; the two animations are viewed on the same time but form different monitors.

The process proposed is conceptually described above.

## 5. CONCLUSIONS AND RECOMMENDATIONS

An efficient method for integrating cost to 4D CAD models for construction has been developed. A key feature of the method is a software application, TriVera, that facilitates the integration process and allows for the display of cost at the same time sequence as the construction schedule animation .

The proposed method consists of a 5-step process that allows for easy development of cost estimates that can be used both for cost estimating and cost control. Additionally, the process provides the project participants, and primarily the project managers, with the ability to analyze and visualize multiple design alternatives in order to develop the most cost-effective solutions. It consequently allows for better control and decision making over different constructability issues and schedule scenarios, providing in this manner a linkage between constructability, 4D, and cost estimating.

As part of future research the cost visualization process needs to be fully automated and fully integrated into 4D CAD. At this point, the selection of cash flows and their import in the animation software is performed manually.

The applications of this process can include all civil works such as buildings, civil infrastructure, and industrial projects. It could also be used within an owner/ contractor organization during the development of cost estimates and for reviewing constructability plans. The time and the cost required for the development, initially of the 3D model and sequentially of the 4D model, restrict the use of the process to projects in which constructability and/ visualization pose a major challenge. In these cases it is required for assisting all project participants to understand interrelated construction sequence and budget issues. As part of decision-making in large scale projects, it can facilitate related procedures and allow for faster project authorization

## REFERENCES

- [1] Bennet, C., and S.. Ditinger: Bechtel Automated Lift Planning System” Robotics for challenging Environments,” New York, N.y., ASCE, 1994
- [2] Vargese, K., and J.T. O’Connor, “Routing Large Vehicles on Industrial Construction Site,” Journal of Construction Engineering and Management 121.1, (1995) 1-12.
- [3] Ling, Kuo-Liang, and Carl T.Haas, “An Interactive Planning Environment for Critical Operations,” Journal of Construction Engineering and Management (1996) 212-22.
- [4] Staub-French, Sheryl and Martin Fischer, “Practical and Research Issues using Industry Foundation Classes,” 2002, Center for Integrated Facility Engineering. Available <http://www.civil.ubc.ca/faculty/Staub-French/Index.html/> November 2003.
- [5] IAI North America, 2003.
- [6] Timberlina, CAD Integrator, 2003, Available: [http://www.timberline.com/include/pdfs/cad\\_intergrator.pdf](http://www.timberline.com/include/pdfs/cad_intergrator.pdf). October 2003.
- [7] Staub-French, Sheryl and Martin Fischer “Formalisms and Mechanisms Needed to Maintain Cost Estimates Based on IFC Product Model,” ICCCBE-VIII, Stanford University, 2000.
- [8] Elzarke, Hazem, “Computer Integrated Construction for Small and Medium Contractors” ASCE 37<sup>th</sup> Annual Conference, Denver Colorado, 2001. 255-62.
- [9] Gould. Frederick E., and Nancy E. Joyce, *Construction Project Management.*, Second Ed. Upper Saddle River, N.J. Pearson Education, 2003.
- [10] Holness, Gordon and V. R. Smart , “IM for Project Management,” January 2003, ASHRAE, Available: [http://www.leanconstruction.org/pdf/holness\\_1pdf](http://www.leanconstruction.org/pdf/holness_1pdf). November 2003.
- [11] Lee, Angela, et al. “Developing a Vision for an nD Modeling Tool,” CIB W78 Conference, Aarhus School of Architecture, Denmark, International Council for Research and Innovation in Building and Construction, 2002.
- [12] McKinney , K.and Martin Fischer, “Generating, Evaluating and Visualizing Construction Schedules with CAD tools,” *Automation in Construction* 7.6, 1998, 433-47
- [13] Retik A.and a.Shapira, (1999), “VR-based Planning of Construction Site Activities,” *Automation in Construction* 8.6 (1999) 671-80.
- [14] Saad I. M and D.and Batie, “The Science and Technology of Building 4D Construction Model”, 2002, Southeast Section Conference ASEE, Available: <http://www.ecu.edu/~ciitr/ASEE2002>, PDF. December 2002
- [15] Sriprasert E.,and N. Nashwan Dawood “Potential of Integrated Digital Technologies (IDT) for Construction Workforce Instruction,” Conference at Chalmers, Gothenburg, Sweden, AVR II, 2001, 136-45.
- [16] Feingenbaum, Leslie. *Construction Scheduling with Primavera Project Planner.* Second ed. Upper Saddle River, N.j., Pearson Education, 2002.
- [17] Fischer, Martin, and Calvin Kam, “4D Modeling Application Case Studies,” 2001 SCIENE Workshop on 4D modeling: available <http://www.scpm.salford.ac.uk/siene/4DApplicationofStudies-3pdf>. October 2003.
- [18] Liapi, K., “4D Visualization of Highway Construction Projects” IEEE. Seventh International Conference on Information Visualization Conference, London, GB, 2003, <http://www.scpm.salford.ac.uk/siene/4DApplicationOStudies-3pdf>. October 2003.