Virtual Reality Applications for power infrastructure planning

Andreas Hoepfner
Fraunhofer Institute for Factory Operation and Automation IFF
Germany

Ralf Opierzynski
Fraunhofer Institute for Factory Operation and Automation IFF
Thailand

Przemyslaw Komarnicki
Fraunhofer Institute for Factory Operation and Automation IFF
Germany

Zbigniew A. Styczynski
Otto-von-Guericke University Magdeburg
Germany

SUMMARY

The objectives of future projects in field of infrastructure development are becoming increasingly complex, their constraints increasingly differentiated and the need for interdisciplinary and sustainable solutions increasingly clear (e.g. trends toward megacities, intelligent networks, smart grids, etc.). In addition to technical issues, additional demands are becoming priorities, e.g. intensified and early involvement of stakeholders (e.g. affected citizens, environmental protection agencies, government representatives, etc.) in development as is the establishment of broad acceptance of a project among the public. Experience has demonstrated that inadequate consideration of these aspects can delay project considerably and thus ultimately burden utility companies financially. Innovative virtual reality (VR) technologies will be used to meet these challenges in the future.

This paper describes how the systematic development of these technologies enhances the effectiveness of methods of infrastructure development and creates significant value added in projects. Work in VR environments is based on photorealistic and accurately scaled 3-D models of planning sites and their environs and the infrastructural elements. Select methods of 3-D modeling are presented in a brief overview and their uses in virtual interactive planning and development environments are outlined. Among other things, they facilitate informative discussions of proposed alternatives, long before concrete plans have been implemented in reality. The related virtual development and analysis tools are described in-depth, taking overhead line planning. Initial experiences with the technology’s use, which have been acquired in European and German infrastructure projects, are referenced.

This paper provides insight into the results achieved in work with the technology and closes by describing future directions of research and the potentials for infrastructure development.

KEYWORDS
Virtual Reality, Visualization, Power System Planning, Overhead Line, Transmission Corridors

andreas.hoepfner@iff.fraunhofer.de
1 Introduction

Future infrastructure development will grow in complexity and reflect the increasingly varied basic conditions and the need for interdisciplinary and sustainable solutions (e.g. trends toward megacities, intelligent networks, smart grids). This will affect the intensified and early involvement of all stakeholders (e.g. affected citizens, environmental protection agencies, government representatives, etc.) in the development processes as well as the establishment of broad acceptance of projects among the public (Schweizer-Ries, 2010). However, necessary communication in established, sequential project structures often only begins after a multistage planning phase. This approach now appears outmoded since little can be undertaken to alter a project at that time without additional costs and delays.

Integrated methods of planning, which facilitate intensive stakeholder networking and early involvement of residents affected by a project, hold crucial potential for improvement. New developments in virtual reality (VR) enhance forms of interdisciplinary communication and collaboration, thus responding to the steadily growing complexity of projects (Lutz, 2005). Photorealistic 3-D models paired with VR work and analysis systems facilitate discussion of plans for infrastructure actions, long before their actual implementation. Only a project planning communicated understandably at an early stage will be understood holistically by the stakeholders and broadly accepted by residents affected by it.

This paper describes how the systematic development and application of virtual reality technologies renders work methods more effective and generates value added in infrastructure planning, especially in area of power system. Methods of 3-D modeling are examined briefly and, taking overhead line planning as an example, their uses in virtual interactive planning and development environments are outlined. Following a recapitulation of the technologies and results achieved, directions for future research are presented.

2 Virtual Landscape and Built Environment Model

A virtual 3-D model of the environment (landscape and built environment) is an underlying element of the methodology. A wide variety of raw data defined by technical standards and modeling methods are available to generate such virtual 3-D models. The basic components of 3-D models are:

- a digital terrain model (including transportation infrastructure, bodies of water, etc.),
- buildings and built structures (including bridges, sight obstructions, etc.),
- vegetation and
- street furniture (including streetlights, traffic signs, benches, etc.).

The requisite quality of the individual model components has to be defined at the start of the modeling phase. The model’s level of abstraction, its accuracy and the required currentness of the data are brought in line with the available resources.

A multitude of methods and software tools are available to generate the kinds of digital terrain models (DTM) used in virtual reality (Li Z.L. et al., 2004). The creation of a triangulated irregular network (TIN) is ideal for integrating them in real time visualizations. Combined with orthophotos (aerial photographs that are free of distortion and true to scale), such a model can be extremely meaningfully and effectively visualized (see Figure 1).

![Figure 1: Digital terrain model, based on a TIN and digital orthophotos](image)
3-D building models are often differenced according to their level of abstraction. The definition formulated by the Special Interest Group 3D (SIG 3D) specifies five levels of detail (LOD) and is excellently suited for structuring infrastructure planning tasks (Gröger et al., 2007). 3-D building models with an LOD of 1 to 2 are often sufficient for infrastructure planning (see Figure 2). Particularly relevant urban areas may require LOD 3.

![Figure 2: a) LOD 1: Block model; b) LOD 2: Roof type and orientation; c) LOD 2 textured; d) LOD 3: Geometrically finely differentiated architecture models](image)

Vegetation is crucially important for the intelligent planning of extended infrastructures with larger zones of visual impact. Incorporating natural vegetation in planning raises the chances of an intelligent overhead line solution (Gerhards, 2003). Usually, the growth heights of vegetation can be obtained by analyzing digital surface models (DSM) and digital terrain models (DTM). When tree species are added, virtual vegetation is depicted authentically. This enhances the quality of the virtual planning environment (see Figure 1).

3 Virtual Interactive Technologies for Planning, Analysis and Communication

VR technologies efficiently support the phases of planning and development and are even being effectively employed to subsequent operation and maintenance (Lipiec, 2011, Arendarski, 2008). A component library containing every essential 3-D element (towers, lines, protection components, etc.) can be used to integrate a planned electrical infrastructure easily in environment models created with the technologies described above (see Figure 3).

![Figure 3: Photorealistic 3-D model of an overhead line in a virtual interactive environment; a) holistic overview; b) close-up](image)

Regional and corporate elements can be added to such libraries to ensure the authenticity of the 3-D representation. Infrastructural elements are integrated manually or automatically through interfaces to GIS and CAD systems. Ultimately, a realistic model of infrastructural actions in the actual surroundings is created. Users can experience the surroundings from a first-person perspective in the virtual environment. They can change their own view in real time and examine virtual contents in depth. Users have maximum freedom and can view both holistic overviews and freely selectable close-ups (see Figure 3).
The supplemental, non-photorealistic visualization of planning concepts and legal constraints on planning, e.g. zoning and clearance zones resulting from line routes, make the view not only vivid but also holistic (see Figure 4). The informational content and plausibility make the overall presentation superior to predefined presentation media (e.g. videos, pictures, graphics, etc.).

**Overhead Line Planning as an Example Optimization of Alternatives**

Impacts on the surrounding environs from electrical infrastructures (overhead lines, cable routes, transformer stations) and health hazards feared from electrical and magnetic fields harbor considerable conflict potential and reaching a consensus is often difficult. On the one hand, impacts on a landscape are difficult to assess and quantify objectively. On the other hand, conventional planning tools limit any discussion of such impacts. Uncertainty about the extent of future environmental impacts is often accompanied by high emotions. Virtual interactive technologies facilitate objective discussions and even expedite projects.

In principle, directly affected residents form their opinions based on expected changes in their surroundings and resultant impacts on their personal spheres. Methods of simulation therefore ought to be geared toward analyzing a situation holistically and examining individual locations concretely.

Methods of color coding virtual models, like those employed to evaluate urban planning (Pamanikabud, 2010) or monitor grid operation (Overbye, 2008), can be adapted and refined to do this. Based on defined rules of calculation, the presence of certain attributes (e.g. noise, electrical fields, etc.) in local regions of a model can be ascertained in virtual environments. The resultant analytical values dictate the color coding. Overhead line planning provides an excellent example that explains how virtual technologies concretely support the objective analysis and resolution of basic planning problems in the energy sector.

**Analysis of Visual Factors**

An electrical infrastructure’s visual impact on a landscape is an initial criterion that significantly affects the planning of a line route. A visual analysis in a virtual 3-D model identifies the regions where a new infrastructure will be directly visible and thus the landscape will be affected. A color coded 3-D model conveys a differentiated and quantifiable impression of the visual impact (see Figure 5a). Whereas a visually perceptible impact is expected in the red zones, none is anticipated in the green zones. In addition to direct visual contact, other input variables, e.g. the number of or distance to visible towers, can be incorporated when values are calculated. Existing sight obstructions, e.g. buildings and vegetation, minimize visual impact, especially in densely populated areas.
Functions for the analysis of individual locations can be added. A specific location in the virtual 3-D model can be interactively selected and examined in detail. The overall photorealistic impression of the virtual environment is retained and the infrastructural elements visible from the defined point of view are highlighted with color (see Figure 5b).

The aforementioned analysis functions can be used to discuss planning alternatives and objectively identify weaknesses. A multitude of actions can minimize and compensate overhead lines’ impact on a landscape (Gerhards, 2003). Appropriate actions, e.g. planting of new vegetation, can be simulated and evaluated in a virtual environment beforehand. In addition to 3-D libraries, basic functionalities to model objects and simulate vegetation growth are also needed. In conjunction with the visual analysis functions, this creates new and farther reaching options to optimize and iteratively improve line routes.

**Analysis of Indirectly Perceptible Factors**

Indirectly perceptible factors, e.g. the electrical and electromagnetic fields emitted by the infrastructure, can also be visualized and analyzed in the VR environment. Field simulation programs deliver the information needed (Kiessling, 2001). The results of a field simulation or the technical simulation model itself can be implemented to the VR-Application and analyzed in a virtual model in relation to the legal thresholds, regulated by laws and technical standards. ICNIRP Guidelines (ICNIRP, 1998) and European Union’s recommendations (EU, 1999) can be applied. The calculation underlying the visualization can also be adapted to basic regional conditions.

The available methods of analysis enable users to understand projects rapidly and holistically.

**4 Conclusion and Outlook**

This paper describes means to systematically develop and apply virtual reality technologies to plan electrical infrastructures, first by outlining the basic methods of modeling and work in virtual interactive environments and then by explicating the potentials of virtual interactive tools in the planning and development of electrical infrastructures. The value added generated by virtual reality technologies in project development is illustrated by the example of overhead line planning. The benefits of employing VR technologies for infrastructure development have already been demonstrated in various application projects (see Figure 6).

![Figure 6: Realization example](image)

Potential applications for the technologies and methodologies increase as the quality of the VR systems increases (realism in the representation, dynamic elements of urban space, acoustics, etc.). Extending the range of information and functions will make it possible in the future to perform interdisciplinary analyses in virtual reality soundly and extremely reliably, which also incorporate economic and ecological aspects for instance. This will make it possible to rigorously further pursue the basic idea of holistic project development and continuously expand the potential virtual reality applications for planning and discussions of acceptance.


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Short Bio-data of Main Author

Andreas Hoepfner holds degrees in architecture and computational visualistics. He is in charge of the Built Environment Visualization Group at the Fraunhofer Institute IFF. His research work is currently focused on the development of VR technologies that support the planning and analyze acceptance of urban and infrastructure development.

Short CV of the Main Speaker

Ralf Opierzynski earned his Diplom degree in Production Engineering from Otto von Guericke University Magdeburg in 1996. Since 1996, Mr. Opierzynski has been working at the Fraunhofer Institute for Factory Operation and Automation IFF in Magdeburg, Germany where he focuses on the fields of environmental information systems, resource management systems and sustainability management. In 2005 he became head of the institute’s International Competence Center Logistics (ICCL). In September 2008 he moved to Bangkok, Thailand in order to establish and operate an ASEAN Regional Office NGO non-profit on behalf of Fraunhofer IFF, Germany.

Mr. Opierzynski has headed and successfully completed numerous international projects implementing IT aided sustainability management systems. Project activities were located primarily in Indonesia, Malaysia, the Philippines, Thailand, Taiwan and Vietnam. Apart from concrete company projects, Mr. Opierzynski has also headed and completed numerous training and transfer projects (e.g. train-the-trainer projects) in the sector of sustainability management and business controlling. In the last 11 years he has trained some 2.500 participants from industry, research and governmental institutions and NGOs. Mr. Opierzynski is a member of the Society of Information Technology (Germany), the Association of German Engineers (Germany), the Asian Society for Environmental Protection (ASEP/Thailand) and the International Green Productivity Association (IGPA/Taiwan) and the Asia Pacific Roundtable for Sustainable Consumption and Production (APRSCP/Philippines).

Contact:
Ralf Opierzynski
Head of Office Bangkok

Fraunhofer Institute for Factory Operation and Automation (IFF)
Magdeburg, Germany

Fraunhofer IFF ASEAN Regional Office NGO Thailand
State Tower (RCK Tower)
1055/550 Silom Road, Floor 29th
Khwaeng Silom, Khet Bangrak
Bangkok 10500
Thailand
Tel. (GER) +49 172 319 8506
Tel. (TH) +66 812 855 465
Tel. (Office) +66 2630-8644
Fax (Office) +66 2630-8645
ralf.opierzynski@iff.fraunhofer.de
www.iff.fraunhofer
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By: Fraunhofer Institute for Factory Operation and Automation (IFF), Magdeburg, Germany

Cutting-edge Virtual Reality Applications Improve the Planning of Complex Energy Infrastructures

Throughout the world, intelligent development and ubiquitous availability of well developed infrastructures are crucial to sustainable economic growth and improved quality of life. The objectives of future projects are becoming increasingly complex, their constraints increasingly differentiated and the need for interdisciplinary and sustainable solutions increasingly clear (e.g. trends toward megacities, urbanization, electric vehicles, etc.). In addition to technical issues, additional demands are becoming priorities, e.g. intensified and early involvement of stakeholders (e.g. affected citizens, environmental protection agencies, government representatives, etc.) in development as is the establishment of broad acceptance of a project among the public. Experience has demonstrated that inadequate consideration of these aspects can delay projects considerably and thus ultimately burden utility companies financially.

This paper introduces innovative tools for sustainable interactive planning of electrical grids on the basis of virtual reality (VR), which respond to the aforementioned challenges. It describes the basic potentials of virtual reality technologies and explains the methodological approaches to their use for specific applications. Initial experiences with the technology’s use, which has been acquired in European and German national infrastructure projects, are also presented.

Virtual interactive systems furnish the potential to establish new forms of interdisciplinary communication and collaboration in pertinent development processes so that increasingly complex contents can be communicated effectively. Novel virtual 3-D models are ideal for this. Virtual models of structures planned for construction are more realistic than ever before. This supports simulation and facilitates meaningful discussion of various alternatives long before construction on power lines really begins, for instance. Virtual model environments enable everyone involved in a project and residents affected by redevelopment to rapidly and accurately understand planned developments in detail without requiring prior technical knowledge. A project idea can only be broadly accepted and implemented in keeping with its schedule and budget when the intentions have been communicated clearly and comprehensibly for everyone involved including affected residents. The potential value added for the communication and development of major construction and infrastructure planning projects is readily apparent.

In addition, the tangible benefits of VR technology are significantly enhanced by the potentials for interaction and the integration of methods of simulation and analysis. Users can interactively intervene in virtual scenarios, vary 3-D models and evaluate different design alternatives by using methods of simulation and analysis.
Other benefits of this new technology are readily apparent. Since not only visual and acoustic factors but also indirectly perceptible variables are visualized virtually and included in any analysis of a project, users not only comprehend a project faster and better but also holistically. VR technologies support interdisciplinary and cross-organizational discussions especially effectively.

In closing, the results of research and development thus far are reviewed and pressing strategic issues are specified, which are crucial to implementing virtual reality technologies in the energy industry even more efficiently and effectively.

Contact:
Ralf Opierzynski
Head of Office
Fraunhofer Institute for Factory Operation and Automation (IFF)
IFF Fraunhofer Regional Office ASEAN
State Tower (RCK Tower)
1055/550 Silom Road, Floor 29th
Khwaeng Silom, Khet Bangrak
Bangkok 10500, Thailand
Tel. (TH) +66 812 855 465
Tel. (Office) +66 2630-8644
Fax (Office) +66 2630-8645
ralf.opierzynski@iff.fraunhofer.de
www.iff.fraunhofer.de
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Ralf Opierzynski / Andreas Hoepfner
Fraunhofer Institute for Factory Operation and Automation
IFF Magdeburg, Germany / Thailand

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Fraunhofer Profile in 2010

60 Institutes
18,000 Employees
€1.7 Billion Research Budget

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Indonesia
Dr. Ida-Bagus Kesawa Narayana

Fraunhofer IFF Regional Office ASEAN, Bangkok, Thailand, Mr. Ralf Opierzynski
Outline

- Virtual reality (VR) in Brief
- Virtual power generation and transmission
  - Model projects
  - Goals and benefits
  - Concept and model components
- VR applications
  - Power generation
  - Power transmission
- Prospects for a practical application
Virtual Reality (VR) in Brief

Virtual reality (VR):
- VR is a computer-generated (virtual) 3-D environment in which one or more users may interact in real time.
- Virtual environments furnish different levels of immersion.

Multisensory channels
- Visual
- Auditory
- Tactile
Virtual Power Generation and Transmission

Goals
- Intelligent configuration and reconfiguration of the electrical infrastructure
- Power generation and transmission

Benefits
- Effective analysis and planning tools
- Fast and effective communication of issues to everyone involved
- Lower costs and shorter planning periods
- Avoidance of conflicts and preservation of image

Model projects
- Wind park development
- Electrical grid and line planning and implementation

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Michael Schenk
Magdeburg, 2011
Virtual Power Generation and Transmission

Main 3-D model components

- Terrain and soil
  - green spaces, streets, etc.

- Buildings, plants and infrastructure
  - different levels of details (LOD)

- Vegetation and other objects
  - different tree species, streetlights, etc.

- Factual and background information
  - interactively retrievable
  - lot and building information

- Interactive functionalities
  - exploration, simulation and analysis
Virtual Power Generation and Transmission

Different levels of terrain detail

Terrain visualization data sources
- Digital elevation models (DEM)
- High resolution aerial images
- Topographic information systems and cadastral surveys (information on land use)

Terrain visualization creation
- Generation of a triangulated network (TIN) from the DEM
- Generation of textures, e.g. from aerial images
- Detailed representation of urban areas based on cadastral survey information and texture library
Virtual Power Generation and Transmission

Different levels of building detail

- Efficient use of project resources
- Effective use of different modeling methods
- Different levels of detail (LOD) based on the individual priorities given different objects
VR Power Transmission Applications

Virtual interactive power infrastructure platform

- Simulation and communication of planning with decision makers, planners and residents
- Creation of acceptance among the population
- Presentation of actual situations and planning alternatives
- Customized object catalog
  - over 20 specific tower types
  - variations of subtypes
  - allowance for material properties (line sag as a function of temperature)
- Linkage of clear 3-D models with simulation results
VR Power Transmission Applications

System Functions

- Interactive planning and presentation functionalities
  - tower placement, relocation and switching
  - several stranding functions
  - general planning functionalities
  - measurement and analysis

- Automatic system processing
  - safety zones under lines
  - manipulation of buildings and vegetation
  - physical features, e.g. line sag
  - visibility test
  - etc.
VR Power Transmission Applications

Simulation and analysis

Simulation result integration:

- VR combines emotional perception and objective analysis
- Plausible and traceable visualization
- Enhanced informational value of the overall visualization and acceptance among users
- Applications in infrastructure planning:
  - interactive visibility analysis of technical assets
  - expansion of electromagnetic fields

VR visibility analysis of an overhead high voltage line
VR Power Generation Applications

Field of application: Renewable energies

- Environmental impact of wind energy converters
  - visual impact in a landscape
  - shadows cast by rotor blades
  - aircraft warning lights
  - low frequency noise emissions

- Need in the field
  - basis for holistic planning for developers
  - quickly understandable, accurate communication with residents affected by a project
  - formulation of sustainable and accepted consensus solutions
VR Power Generation Applications

Systematic use of auditory systems in the Elbe Dom

- **Holistic, realistic perceptions**
  - visual and acoustic factors
  - enhanced immersion
  - VR is an accepted basis for decisions

- **Basis for acoustic simulation**
  - wind energy converter indicators
  - validated acoustic models and hardware

- **Planning aspect**
  - impacts of planning on the overall visual and acoustic impression
  - actual and target state
  - discussion of alternatives (plant types, site, etc.)
  - simulation of compensatory measures (vegetation for noise control)
Prospects for a Practical Application in Malaysia

Project structure and work

1. Initial analysis (10%)
2. Concept / organization (10%)
3. Data management, integration (15%)
4. Modeling (50%)
   a) Terrain model, b) Buildings (LOD 1 – 4),
      c) Vegetation, d) Illumination, etc.
5. Integration (10%)
   a) Interaction, b) Customization of features,
      c) Object-specific information, etc.
6. Software and hardware installation (5%)

- Costs vary from project to project based on their specifics:
  Quality of initial data, desired modeling accuracy, modeling methods, system development, etc.
Prospects for a Practical Application in Malaysia

Our services

Technology and development partnership

- Creation of initial 3-D models (upgraded and maintained by the municipalities)
- Software and software development
- Innovative projection technology
- User qualification and support
  - data and application standards
  - ICT systems evaluation
  - pilot project coaching
  - Fraunhofer IFF software support when generating virtual city models
Prospects for a Practical Application in Malaysia

Summary

- The Fraunhofer IFF has successfully implemented 3-D city visualizations throughout Europe.
- Systems and methods can be adapted to applications and local conditions.
- One technology is applicable to different disciplines.
- A holistic approach generates synergies.
- Progressive development assures sustainability: Primary application, pilot project, etc.
- The Fraunhofer IFF enters technology partnerships with local partners.
Benefits and Perspectives

- Establishment of a Partnership with the biggest applied R&D Organization in Europe (plus its networks) (60 institutes, 18.000 employees, 1.7 Billion Euro Research Budget)

- Exclusive Agreement on VR Applications in the energy sector in Thailand

- First-mover in terms of applying innovative VR Technologies in Thailand (cost saving potentials, competitive advantage)

- Access to cutting-edge VR Methods, Know-how, Expertise and Applications (German Innovation Clusters)

- Enhancement of existing training & qualification / planning procedures by applying customized VR-Applications (complementary)

- Establishment of a “Centre of Excellence” on VR Applications (long term perspective)
10 good ideas a day
keep your competitors away
Co-ordination and Management of the Activities in the ASEAN-Region

by the
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- References

- Reputation (IFF / FhG)

- Continuity

- Reliability

Contact:
Ralf Opierzynski
Head of Office
IFF Fraunhofer Regional Office ASEAN
State Tower (RCK Tower)
1055/550 Silom Road, Floor 29th
Khwaeng Silom, Khet Bangrak
Bangkok 10500, Thailand

Tel. (TH) +66 812 855 465
Tel. (Office) +66 2630-8644
Fax (Office) +66 2630-8645
ralf.opierzynski@iff.fraunhofer.de
www.iff.fraunhofer.de