Discussion of "Areas of Application for 3D and 4D Models on Construction Projects" by Timo Hartmann, Ju Gao, and Martin Fischer

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The authors provide a good categorization framework for application areas for 3D and 4D models in construction practices. It will be helpful for the practitioners in finding the most beneficial applications of 3D and 4D models on their projects and also for the researchers in identifying the most promising areas of research. The authors have already explored different possible areas of applications and research; however, the objective of this discussion is to make some additional observations about a few issues related to future research areas for 3D and 4D models. The discusser feels that more points may be incorporated in future studies in order to help readers better understand the authors' observations.

Although 3D computer-aided drafting (CAD) models are strong visualization tools, they consist of points, lines, polygons, and solids with no topology and no link to a database. As mentioned in the paper, there is a major revolution of building information modeling (BIM) in the CAD world. BIM is a kind of 3D modeling that includes topology and may be linked with a database. It is a full building life cycle management tool from construction to day-to-day operations to ultimate demolition. The authors mentioned that 3D/4D models, as well as BIM, need to be researched to determine their future use in different applications areas. In the discusser's opinion, it would have been better if the authors had specified that 3D CAD and 4D modeling should be researched for application in 3D topology, or the industry needs the integration of BIM with 4D tools, or researchers should study the application of 4D tools during the project life cycle (as mentioned in the paper), or the 3D and 4D modeling capabilities of BIM should be enhanced.

The 4D models require application-level integration to fulfill project requirements such as quantity takeoffs, cost estimation, energy simulations, etc. Hence, software from various disciplines is being used to fulfill such requirements. Architects, engineers, builders, owners, and operators face challenges because different information formats are used to represent the graphical and nongraphical information for a project and this data is difficult to consolidate (Isikdag et al. 2008). During the planning process when using 4D models, planners have to repeatedly reorganize, interpret, and combine the information collected from different software. This process is tedious and frequently produces errors. Therefore, lack of interoperability is a major obstacle to effectively combining information from different sources. BIM provides solutions for overcoming the interoperability problems that result from the fragmented nature of the construction industry, as the authors also stated. However, in the discusser's view, readers may benefit if the authors make their research direction more clear with respect to BIM. Do the authors recommend BIM for practitioners to deal with interoperability problems, or should research focus on the application-level integration of different commercially available tools being used in the construction industry?

The 3D (up to floor-level detail)/4D modeling and geospatial information together support neighborhood planning, improve delivery of different services, assure adequate safety and security planning, plan line of sight communications, optimize way finding, support transportation planning, and improve customers' awareness of their access to retail services (Smith and Friedman 2004). Yet 3D/4D modeling and BIM lack geospatial analysis features such as evaluation of new building locations for compliance with constraints, including:

- Selection of a suitable site satisfying the project requirements;
- Possibility of construction site flooding;
- Drainage planning for the site in case of flooding;
- Planning for firefighting in case of fire;
- Building safety, emergency, and security planning;
- Vehicle entrance planning for different access routes to construction site; and
- Availability, flow direction, and distance of existing water and wastewater systems from the construction site.

3D/4D models and BIM are not completely geospatial in nature, whereas in geographic information systems (GIS) objects are associated and perceived together with their surroundings. However, the level of sophistication, particularly in 3D modeling, is superior in CAD and BIM tools. Still, GIS has its own strengths as a geospatial analysis tool that are missing from 3D/4D models. For geospatial analysis, 4D models and BIM still need application-level integration with GIS (Isikdag et al. 2008). Keeping the importance of geospatial analysis capabilities in view, contractors and organizations create, store, and share information about 3D models up to floor-level details and their surrounding geography together. The discusser feels that requirement to integrate 3D and 4D technologies with GIS to fulfill a project's geospatial requirements may be mentioned.

GIS draws by using point, line, and polygon features and links its drawings to a database, but it is not made to do sophisticated 3D modeling. Because of inherent topology, GIS understands relationships and can perform analysis of aspects of a project, such as what component is next to another, what component is within another, what component intersects another, and it can display results of this analysis graphically. It is also capable of recognizing spatial and nonspatial information queries, which the existing 3D and 4D models cannot. GIS is used to meet requirements (database management, quantity takeoffs, cost estimations, materials layouts, real-time schedule monitoring, site layout development, route planning, topographical visualizations, progress monitoring, etc.) of a construction project that 4D models cannot (Bansal and Pal 2007; Miles and Ho 1999). The authors have established an excellent application of 4D modeling in the schedule review process, but in the discusser's view, schedule review of complex construction projects, such as earthen dams, where topography plays a major role, could not be modeled by 4D without geospatial capabilities (Zhong et al. 2004). Therefore, in the discusser's view, CAD users in the construction industry should not underestimate GIS. 3D modeling up to floor-level details combined with geospatial capabilities has its own significance because large facility management companies have a foot in both CAD and GIS systems.

GIS imports CAD data formats or connects to CAD layers; however, this integration cannot solve the building and geospatial information integration problems because the method depends on either the CAD or GIS application and cannot be used to tightly integrate the whole range of data (Aouad et al. 2007). The discusser feels that the construction industry needs spatial analysis features that are available in GIS and that 4D models and BIM lack. Keeping in view that GIS and BIM/3D/4D models cannot be adequately integrated, the GIS community has also explored different features, including generation, visualization, and evaluation of construction schedules (Bansal and Pal 2008); quantity takeoffs; cost estimation (Bansal and Pal 2007); construction process control (Poku and Arditi 2006); and direct sunlight visualization (Bansal and Pal 2009), in GIS that are already in commercially available tools. In the discusser's opinion, the GIS community is doing research for the construction industry in a few areas that are already being explored by 4D/CAD/BIM world, while the 4D/CAD/BIM community is doing research on areas that are already being explored by the GIS world. Even after the development of 4D models and BIM, the construction industry is still looking to bring together capabilities from different environments, such as full editing and 3D visualization from CAD systems, the ability to manage large data sets from DBMS, and spatial analysis from GIS. This research field remains unsettled; therefore, the discusser feels the authors may specify the requirement of integration of 3D and 4D models with GIS; otherwise, 3D and 4D models need to be developed for spatial analysis.

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Closure to "Areas of Application for 3D and 4D Models on Construction Projects" by Timo Hartmann, Ju Gao, and Martin Fischer

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We agree with the commenter's suggestions that researchers should incorporate more areas in our framework, but only if they can document evidence of the area's actual use in practice. As we mention in our paper, "We expect that the number of different application areas is larger than our framework currently reflects and will increase in the future." To provide others with illustrations of possible areas, we chose to focus on two examples "that researchers have already examined…but for which the analysis results of the test cases do not show any evidence of application." It was not our intent, nor would it have been useful for the paper's scope, to attempt to provide a detailed, maybe even comprehensive, assessment of all application areas that are being researched at the moment. We only added the section on future applications to trigger thoughts and discussions among other researchers of where the "3D/4D journey" can lead the construction industry. Reading the discussion we can conclude that this attempt was successful, and we hope that the paper, its discussion, and this closure will lead to further critical debates.

Nevertheless, we would like to caution researchers and practitioners who wish to extend the framework with new areas. The paper's goal was to summarize practical applications of 3D/4D models in the construction industry with a documented practical potential to improve the actual design and construction of the built environment. We chose this goal because we felt that much empirical research in the area had not documented the practical implementations and the practical utility (Dewey 1938) of the area. In fact, most previous research used practical illustrations only to provide evidence for the technical feasibility of developing 3D/4D model prototypes. The main contribution of the paper is different in that it presents only projects on which practitioners had made a serious attempt to integrate the use of 3D/4D models into their work practices. All case projects applied 3D/4D models in practice. In none of them were the 3D/4D data used with the sole purpose of collecting research test data to provide evidence for the functionality of early 3D/4D model prototypes. This action-based research approach (Hartmann et al. 2009) enabled us to provide a unique description of advanced construction management practice. In addition to some of our other work that focuses on single application areas (see, for example, Hartmann and Fischer 2007), we hope that the paper can inspire other researchers to go beyond the mere development and initial testing of early prototypes toward reporting the results of action research that tests the practical utility of new application areas for 3D/4D models. After reading the discussion, we are concerned that other researchers misunderstood our intention in writing the paper. We see the great danger that these researchers will try to extend the framework prematurely into areas that do not yet provide practical utility.

We will further discuss our concerns by directly addressing the two areas that the discusser puts forward. To the best of our knowledge, the new possible areas suggested in the discussion still lack any documented evidence of an implementation in practice. Because no action research has yet adjusted the technological research efforts with practical decision-making processes, the two areas are still under-technologized (BIM) and over-technologized (GIS). Therefore, they should not be integrated yet in our framework of practical applications of 3D/4D models. In the rest of this closure, we will explain what we mean by under-technologized and over-technologized by raising questions about the two new areas that the discusser suggests for inclusion in the framework.

We refer to BIM as under-technologized because there is still a large gap in our understanding about the technical possibilities of BIM to support practical work processes. In particular, our experience with applying BIM in practice does not support the notion—put forth by the discusser and others, e.g., Succar (2009)—that one integrated information model of a building can technically support all practical data needs throughout the life cycle of a project. Because of performance- and process-related issues, projects need a myriad of different data models that are specifically designed to support the vast amount of decision-making tasks practitioners face during the life cycle of a project. With respect to performance-related issues, computational limitations require that researchers streamline data models to certain specific decision-making tasks at hand. It is, for example, still not possible to navigate a complete 3D design model of even fairly small construction projects without running into significant performance issues that severely hinder the model's usability. This situation has not improved in the last two decades. Therefore, it will be necessary for some time that 3D/4D model applications in all areas rely on specific, custom-tailored building information models that allow the implementation of effective algorithms for data visualization, exchange, and optimization. With respect to process-related issues, the different levels of detail of information required by the many specialists that work on a project present another obstacle for an integrated BIM. It is important for each specialist to be able to switch between the different levels of detail dynamically in order to develop the knowledge required to design and construct a facility (Whyte et al. 2007). A single data model cannot provide this functionality for all practitioners, since a data model cannot anticipate all the meaning of data that will emerge in the largely social design process (Wittgenstein 1973). Unless new advances in the field of artificial intelligence will allow for an automated adjustment of hierarchical object models ontology to different dynamically emergent meanings, it is not possible to support the complex multidisciplinary decision-making tasks during the design and construction of facilities.

To overcome these technical problems, we recommend that BIM researchers develop highly specific data models and algorithms based on an in-depth understanding of the decision-making processes of projects and adjust and test these data models with action research efforts. We realize that this will exacerbate the interoperability challenges. However, interoperability matters only if BIM-based design, engineering, and construction applications exist with the true potential to support practical decision-making tasks. Unless such applications that operate on integrated data models are available, it is an entirely academic exercise to research and develop such integrated models. In summary, we caution against basing development efforts on assumptions about technological possibilities that are not yet feasible—or, in other words, under-technologized. We suggest that researchers use action research to align their assumptions with practical work processes to understand what is technically possible. Hence, to explicitly answer the discusser's only question, we believe that integration needs to occur at the application level and not at the database level. To allow for such an integration, researchers need to align BIM technology with the existing decision-making processes. Such alignment is possible only with action research efforts that are specifically targeted to understand and support specific decision-making processes.

With respect to the second area the discusser suggested—GIS—technically, it is easily possible to integrate GIS and 3D/4D models by referencing 3D/4D models to geospatial coordinates. However, we are not aware of any documented implementation in practice of such an integrated system. Hence, little is known about how such an integration can truly support professional decision-making processes. Intuitively, we also have some doubts about whether such an integration will yield the practical utility that many proponents of such an integration promise. The discusser mentions that an integrated system would allow engineers, for example, to select a suitable site that satisfies the project requirements; to evaluate possibilities of construction site flooding; to support the drainage planning of the site; to support the planning of firefighting activities; to improve the building safety, emergency, and security planning; to plan for vehicle entrance; and to evaluate the availability, flow direction, and distance of utility lines. All these areas of application are of utmost importance during the design and construction of a facility. However, we would like to question whether it is necessary to support such decision-making activities with geospatially referenced 3D/4D models in practice. Practitioners already routinely use GIS systems to support their decision-making tasks. We are not aware of any practical evidence for an added value that an integration between these GIS applications and BIM would offer. Therefore, we refer to the integration of 3D/4D models and GIS systems currently as still being over-technologized; while it is easily possible, technologically, to integrate the two systems, evidence for the practical utility to do so is rather limited. Again, only action-oriented research can clearly show whether the integration of GIS and BIM is an area that researchers should integrate in our practical framework about areas of application of 3D/4D models on construction projects.

To avoid the integration of over-technologized or under-technologized areas, the original paper's framework integrates different application areas of 3D/4D models for which documented evidence for an implementation in practice that is based on action research efforts exists. We suggest that researchers that wish to extend the framework with new areas do so only if such documented practical applications are available for the new area. In this way, they can be sure to suggest only new 3D/4D application areas for which it is possible to develop practical technical solutions (that is, the area is not under-technologized) and which can truly support decision-making tasks of practitioners (the area is not over-technologized). We again want to stress that our discussions of BIM as under-technologized and GIS as over-technologized areas are purely speculative in light of the lack of documented empirical evidence for practical applications. Only an action-based integration in practice can truly show whether one of these areas can provide a pragmatic practical utility. We believe that, as responsible researchers, it is our duty to test our ideas about future areas in practice before we suggest that practitioners apply 3D/4D models to support decision-making tasks in new areas.

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