DEFINING A RESEARCH AGENDA FOR AEC

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The call for whitepapers issued by the organizers of this workshop asks for participants to address two main areas:

- Identification of the research agenda for AEC
- Prioritization of the research needs and measurement of achievements

The process of defining a research agenda for any industry should be a combination of methods and the methods must aim to ensure the comprehensiveness of the topics suggested. The previous NSF CE&M workshop [1] has dedicated (almost) a whole chapter (chapter 4) to identifying research topics in construction. The participants adopted the brainstorming method to generate a research agenda. Given the way this current workshop is organized, I think that two additional approaches should be considered: problem analysis and cross-fertilization. While the three approaches are not disjunctive, I think that a wider range of solutions can be generated when each approach is applied separately. This paper presents three research topics: constructability modeling, wearable robotic machines, and development of better methods of construction education. Each topic was determined using one of the three approaches.

PROBLEM ANALYSIS / CONSTRUCTABILITY MODELING

With the exception of "cookie cutter" residential developments, all construction projects are, even if only to some small extent, different. Each construction project is a prototype with specific objectives and constrains such as time, money, quality, labor (amount and skills), safety policy, etc. The success of a project depends on the knowledge and experience of the participants in planning, design, procurement and field operations. Hence the main challenge of the construction industry is to **identify**, **use** (and) **further develop** the **knowledge and experience** of the participants in the construction process.

The optimum use of construction **knowledge and experience** in planning, design, procurement, and field operations to achieve overall project objectives is defined by CII as "constructability" [2]. The constructability problem can be defined as "achieving the goals of the owner within the constrains (limitations) of the builder."
Constructability research is not new to the AEC community. Three different research branches of constructability can already be identified:

- **Human-oriented research**. Includes managerial and organizational approaches. In this case the constructability knowledge is assumed to lie within the participants in the process and the main problem is timing their participation in the project. Most of the constructability research done to the day is related to this branch. Among the more than forty papers published in this area, the CII Constructability Implementation

Guide seems to be the most referenced one. Articles [3] to [10] exemplify most of the ideas covered by the other papers. This is an area where there is a high probability of high benefits from short-term research.

- **Data/Knowledge Base approach**. Tries to capture the human knowledge in a structured form so it can be used by other humans. Constructability databases [11-14], lessons learned [15,16], and knowledge-based systems[1] [16-20]can be included in this category. Some of the systems developed in this area are already in use (for an overview see [14]). This approach has two main contributions: (one) a quick way to implementing partial results and (two) a systematic way to better understanding the constructability problems. From the point of view of a national AEC research agenda I think this area is past its glory.
- **Constructability Modeling**. Tries to capture and solve the constructability problem by using a computer model of the construction[2]. While all the models developed share the basic concept of object-oriented modeling, the vastness of the subject has led to a multitude of disparate models, each of them focusing on a different aspect of the construction artifact/process. Examples are: design [21-24], construction methods and scheduling [26-29], work spaces [29, 30]. Some more general approaches are taken by proponents of total construction models [26], and the organizations working on standards for interoperability[31, 32]. All the models mentioned above integrate or can accommodate product and process models.

However, none of the three research branches address the constructability problem in a comprehensive manner. They lack the detailed representation of construction operations and the capability to deal with the ramifications of multiple possibilities at each decision stage.

The solution I envision stems from the constructability modeling approach, but is based on modeling the construction operations to a level of detail that allows the application of a theoretically sound optimization procedure to attain the goals of the owner. As stated above, such goals can be minimization of cost, time, use of embedded energy etc. I will call this area of research “formalization of the constructability problem.” The approach is similar to the one taken by the manufacturing industry in the concept of “design for X” [33]. Models and languages of machine operations are used to optimize the design for any desired purpose. The “X” in the “design for X” stands for manufacturability, assemblability, serviceability, or other similar goals. In my view, the formalization of the constructability problem will be based on results that should be achieved in the following two interrelated areas:

1. Construction operations description language. This language should be similar to a high level robot programming language. It should allow the description of the most elementary operations such as the pounding of a hammer, turning of a wrench or reaching of a human arm to tie rebars. The language should allow the description of the movement of construction objects (such as the slide-in-place of a reinforcement stirrup or a piece of HVAC duct) and mechanical equipment in terms of operation,

1 I have used here the term knowledge-based-system in its broadest definition. Some researchers will argue the validity of my decision to include their work in this category. This loose classification was required to allow presenting the point in a more concise fashion.

2 The term construction has a double meaning here: both the artifact and the process.

spatial coordinates, and time. This language should be developed in collaboration with people form robotics, computer science and researchers working in the modeling of human movement, such as sport or dance.

2. Algebra of construction topologic relations. Examples of construction topologic relations are X supports Y, X is_embedded_in Y, X covers Y, X soils Y, X surrounds Y, X supports Y, etc. X and Y are construction objects such as elements, parts, envelopes, activities, etc. Preliminary research performed by the author suggests that it is possible to build an algebra[3] of topologic relations. Through such an algebra all the relevant topologic relations between construction objects can be represented. Such a representation allows easy determination of constructability disturbances (such as interferences, construction impossibilities, disturbances, etc.) and eventually an optimization of the construction artifact/process.

I agree that today both areas seem esoteric and very remote from actual construction problems. However, I believe that by following the old recipes for solving the problems of construction we will only get the same old results. Under the economic pressure of the manufacturing industry old results are not an option for construction. I further believe that, because of its fundamentally new way, this research will allow us to really explore construction problems, it would represent fundamental and basic research in construction.

As with most fundamental research, the question of timing, value and duration of the formalization of the constructability problem are hard to address. Formalization of the constructability problem is certainly a long-term research effort. While it is evident that research in the area of constructability is not “art pour l’art”, separate research is needed to assess the potential direct benefits of solving constructability problems. I don’t believe the research for the formalization of the constructability problem should wait for the evaluation of direct benefits. In addition to the knowledge gained by performing such research, it is worth noting that fundamental research conducted in AEC will certainly improve the image of the profession and attract more talent to construction.

CROSS FERTILIZATION / WEARABLE ROBOTIC MACHINES

There are many technologies and management techniques that are imported from one area of economic activity to another. New materials, controls, and modeling tools are just a few of them. In an effort to capitalize on developments made in other industries, one must start by analyzing the developments that made a significant change in the industries that developed or adopted them. While I am not aware of any study that measured the impact of computers on each branch of business and manufacturing, there is, I believe, little doubt that the most prominent change in modern economy was brought by computers. However, computers do not build buildings. People and machines do. What really allows the leading industries to be so efficient is automation and robotics.

Earlier efforts in introducing robots to construction failed to significantly change the way construction is done [34]. They may be two reasons for this:

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[3] Algebra = The mathematics of generalized (arithmetical) operations.

1. The development of the robotic solutions did not address robotization in a systemic way. They concentrated on developing robots for specialized activities.
2. The robots were adapted to work with construction components that were designed to be handled by humans, therefore they did not take full advantage of the benefits robots can have.

Prefabrication is one way to easily adopt robots in construction, but the construction reality seems to move away from "out of the box" solutions. My vision is an integrated system where one can go to a construction superstore with a 3D CAD project (with the constructability problem already solved) and have all the pieces pre-cut, bar-coded and packed in reverse order by robots in the back-yard. When the building components arrive on site they can be unpacked and installed in the scheduled order. Eventually each project will be delivered with a computer that will help during the construction process and later for building maintenance. All this can be almost done with today's technology and knowledge. The change I suggest has to do with the way such a building will be built. My proposal is to develop "construction force boosters." Construction force boosters are "wearable" robotic machines that extend the range and power of human activities. Today there are no such machines available, but it is easy to imagine how they work. An increase of the force and reach of humans allows the use of larger construction components, and should increase productivity. The research topic I propose deals with the general description and simulation of the construction force booster, as well as an evaluation of the productivity gains it can induce if the construction systems are changed accordingly. Introducing high-tech tools to the construction site may also attract more talented people to the profession. This may be an additional avenue to solve the problem of an aging skilled work force in construction.

BRAINSTORMING / CONSTRUCTION EDUCATION

Brainstorming is effective only if there is a group of people participating in it. I assume the workshop will use the brainstorming technique in the first few hours. Under this subtitle I would like to add one more topic, unrelated to the previous ones. Construction education. Construction is a profession that strongly combines theoretical skills with practical and managerial ones. Educating constructors is different from educating engineers or managers alone. It's a combination of the two. The teaching methods applied should "talk" to both "right brain" and "left brain" people. Development of better instructional tools is imperative if we try to recruit and maintain more talented people. New laboratory approaches and instruments need to be invented in collaboration with psychologists and educators. Some of them will be virtual tools, some will be real "touch and feel" apparatus, and some will be educational games.

References:

1. CII and NSF (1997). How do we use research to improve the engineering and construction industry. Final Report, Workshop Co-sponsored by the Construction Industry Institute and the National Science Foundation, May 13-14, Austin, TX. (NSF Contract#9700436 CMS)
2. CII "Constructability Implementation Guide", Bureau of Engineering Research, The University of Texas at Austin, Publication 34-2, 1. February 1993
3. Radtke, M.W., Russell, J.S., "Project-level model process for implementing constructability" Journal of Construction Engineering and Management. v. 119 Dec. '93 p. 813-31.
4. Russell, J.S., Gugel, J.G., Radtke, M.W., "Comparative analysis of three constructability approaches", Journal of Construction Engineering and Management. v. 120 Mar. '94 pp. 180-195.
5. Gugel,J.G., Russell, J.S, "Model for constructability approach selection" Journal of Construction-Engineering and Management. v. 120 Sept. '94 pp. 509-21.
6. Uhlik, F.T., Lores, G.V., "Assessment of constructability practices among general contractors", Journal-of-Architectural-Engineering. v. 4 no3 Sept. '98 p. 113-23.
7. Gibson, G. E., Jr; McGinnis, C. I, Flanigan, W. S., "Constructability in public sector" Journal-of-Construction-Engineering-and-Management. v. 122 Sept. '96 p. 274-80.
8. Hutchison, A. W., "No more construction delays" Water-Environment-and-Technology. v. 8 July '96 p. 61-3.
9. Kartam, N. A., "Making effective use of construction lessons learned in project life cycle", Journal-of-Construction-Engineering-and-Management. v. 122 Mar. '96 p. 14-21.
10. O'Connor, J. T., Miller, S. J., "Barriers to constructability implementation" Journal of Performance of Constructed Facilities. v. 8 May '94 p. 110-28.
11. Ioannou, P.G., Liu, L.Y., "Advanced construction technology system – ACTS", Journal of Construction Engineering and Management (1989) vol.119 no.2
12. Rasdorf, W.J., Abudayyeh, O., "NIAM conceptual database design in construction management", Journal of Construction Engineering and Management. 6(1) 1992 p. 41-62.
13. Hanlon, E., Sanvido, V.E. (1995). "Constructability information classification scheme." Journal of Construction Engineering and Management (1995) vol.121 no.4
14. Kartam, N., Flood, I., "Constructability feedback systems: issues and illustrative prototype" Journal of Performance of Constructed-Facilities. v. 11 Nov. '97 p. 178-83.
15. Vanegas, J. A., ""A Constructability Lessons Learned System for Infrastructure Rehabilitation Using Digital Image Processing," Proceedings of the Engineering Foundation Conference on Digital Image Processing: Techniques and Applications for Civil Engineering, co sponsored by the National Science Foundation, Kona, Hawaii, February, 1993
16. CII "Lessons learned - The Steps to Success", 1997 CII Conference, SP 97-15.
17. De la Garza, J., M., Alcantra, P., T. "Using parameter dependency network to represent design rationale." Journal of Computing in Civil Engineering, (1997) Vol. 11, No. 2, pp. 102-112

18. Fischer, M., Tatum, C. B. “Characteristics of design-relevant constructability knowledge” Journal of Construction Engineering and Management. v. 123 Sept. '97 p. 253 60.
19. Wiezel, A., Becker, R. “CAD model for performance evaluation.” Building and Environment vol. 31 no.4, 1996, pp.345-361
20. Fischer, M., Tatum, C.B. (1997). “Characteristics of design-relevant constructability knowledge.” Journal of Construction Engineering and Management vol. 123, no.3, 1997, pp 253-259
21. Ford S., Aouad, G., Kirkham, J., Brandon, P., Brown, F., Child, T., Cooper, G., Oxman, R., Young, B., “An informatioin engineering approach to modeling building design.” Automation in Construction 4 (1995) 5-15
22. Gross, M.D., “Why can’t CAD be more like Lego? CKB, a program for building construction kits”, Automation in Construction, 5, 1996, pp 285-300.
23. Hong, N.K., Hong, S., “Entity-Based Models for Computer-Aided Design Systems”, Journal of Computing in Civil Engineering, Vol 12, No. 1, 1998 pp. 30-41
24. Skibniewski, M., Mathur., K., "Evaluating building design for constructability: a quantitative approach", unpublished manuscript, 1997, Purdue University, West Lafayette, Indiana
25. Fischer, M. and Aalami, F. (1996). “Scheduling with Computer-Interpretable Construction Methods Models.” Journal of Construction Engineering and Management, Vol 122, no.4,. 1996, pp 337-346
26. Froese, T., Rankin, J.. “Representation of Construction Methods in Total Project Systems.” The 5th Congress on Computing on Civil Engineering, ASCE, Boston, Oct. 1998, pp 383-394.
27. Sacks, R., Warszawski, A. (1997). “A project model for an automated building system: design and planning phases.” Automation in Construction 7, 1997 pp. 21-34
28. Shaked, O., Warszawski, A., “Knowledge-based system for construction planning of high-rise buildings” Journal-of-Construction-Engineering-and-Management. v. 121 June '95 p. 172-82.
29. Riley, D.R., Sanvido, V.E., “Space planning method for multistory building construction.” Journal of Construction Engineering and Management vol.123 no.2, 1997, pp. 171-80.
30. Akinci, B., Fischer, M., “Time-Space Conflict analysis Based on 4D Production Models”, The 5th Congress on Computing on Civil Engineering, ASCE, Boston, Oct. 1998, pp 342-353.
31. Ghodous, P., Vandorpe D., “A Systematic Approach for Product and Process Data Modeling Based On the STEP Standard”, Computer Aided Civil and Infrastructure Engineering 13, 1998, pp. 189-205
32. Yu, K., Froese, T., Grobler, F., “International Alliance for Interoperability: IFCs”, The 5th Congress on Computing on Civil Engineering, ASCE, Boston, Oct. 1998, pp. 395-406
33. Huang G.Q. (Ed.), “Design for X : concurrent engineering imperatives”, Chapman & Hall ; London, 1996.
34. Warszawski, A., Navon, R., “Implementation of Robotics in Building: Current Status and Future Prospects” Journal of Construction Engineering and Management, ASCE, 124(1) 1998, pp. 31-41

PERSONAL BACKGROUND

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AREA OF TEACHING AND RESEARCH
Computer Applications in Construction, Building Performance, Automation in Construction, Construction Education

PUBLICATIONS:

Archival refereed journal papers:

- **Wiezel, A.**, Walsh, K., Brena, J., " A critical Analysis of an introductory computer course for constructors," Journal of Construction Education, Vol. 3, no 1, pp. 52-63, 1999.
- Senevirante, I., Schexnayder, C., **Wiezel, A.**, "Establishing a Word Wide Presence," Practice Periodical of Structural Design and Construction, ASCE Vol. 4, No.2 pp.69-74, 1999.
- **Wiezel, A**., Becker, R., "CAD model for performance evaluation," Building and Environment, Elsevier Science Ltd., Vol. 31, No.4, pp. 345-361, 1996.
- Becker, R., **Wiezel**, A., "A Computerized System for Performance Integrated Computer Aided Design,"*Architectural Science Review*, Vol. 36, pp. 113-119, 1993.

Refereed national/international conference proceedings papers:

- **Wiezel, A.**, Chasey, A., Schexnayder, C., "Building a Web Site for Construction Organizations", Associated Schools of Construction, Proceedings of the 35th Annual Conference, San Luis Obispo, Ca, Apr. 7-10, 1999 pp. 285-398, 1999

1. Schexnayder, C., **Wiezel, A.**, Senevirante, I., "Construction Professionals and the Internet," Associated Schools of Construction, Proceedings of the 35th Annual Conference, San Luis Obispo, Ca, Apr. 7-10, pp. 349-362, 1999

- Schexnayder, C., **Wiezel, A.**, The use of the Internet as a Tool to Transfer Knowledge, Education in Construction Management, ISBN 695-90209-0-2, Proceedings of the Second A.J. Etkin International Seminar, Haifa, Israel, May 4-6, 1998, pp. 63-72
- **Wiezel, A.**, Measuring the success of virtual tutoring, Proceedings of Frontiers in Education '98, ASU, November 4-7, 1998, pp 987-991

- **Wiezel, A.**, The Real Benefits of the Multimedia-based Educational Environment, Proceedings of the Fifth Congress of Computing in Civil Engineering, Boston 1998, ASCE, pp 288-296
- Schexnayder, C., **Wiezel, A.**, Construction Education Using the World Wide Web, Proceedings of 1998 ASEE (CD-ROM).
- **Wiezel, A.**, Schexnayder, C., Walsh, K., Meeting the Computer Expectations of the Construction Industry, Proceedings of 1997 IEEE International Conference on Microelectronic Systems Education, Arlington, VA, IEEE, 1997, pp.39-40.
- Wiezel, A, Enhancing cooperative learning using distance education, Proceedings of the fifth Congress of Computing in Civil Engineering, Philadelphia, PA, ASCE, June 1997, pp. 65-72
- **Wiezel, A.**, Walsh, K., Brena, J., "A critical Analysis of an introductory computer course for constructors," Associated Schools of Construction, Proceedings of the 33rd Annual Conference, Seattle, WA, April 1997, pp. 153-162.
- **Wiezel, A.** "Performance Integrated Design: A Value Approach," 3rd International Symposium on Applications of the Performance Concept in Building, CIB-ASTM-ISO_RILEM, Tel-Aviv, Israel, Dec. 1996
- **Wiezel, A.**, and Becker, R., "Integration of Performance Evaluation in Computer Aided Design," The SUNY Buffalo 3rd International Symposium on CAD, Buffalo, NY, March 1990.
- (also published in "Evaluating and Predicting Design Performance," edited by Kalay, Y. E., John Wiley & Sons, New York, 1992, pp. 171-181)
- **Wiezel, A.**, and Becker, R, "Development of a Computerized System for Evaluation of the Overall Performance of a Building" The International Conference on CAD/CAM and AMT, Jerusalem, Dec. Vol III section F-4-5, 1989

Book Publishing (Book Chapters)

Wiezel, A., and Becker, R., "Integration of Performance Evaluation in Computer Aided Design" in "Evaluating and Predicting Design Performance" edited by Kalay, Y. E., John Wiley & Sons, New York, 1992, pp. 171-181. (based on presentation at The SUNY Buffalo 3rd International Symposium on CAD).

Sponsored Research

1. **Wiezel**, A.(80%), Becker, R.(20%), *Development of a Computerized System for the Performance Evaluation of Final Designs,* Ministry of Housing, Israel, $40,000, 1987-1989
2. **Wiezel**, A., *Development of a Computerized System for Performance Oriented Design During the Entire Design Process,* Ministry of Housing, Israel, $15,000, 1990-1992
3. **Wiezel**, A., *Automatic Building Design,* Ministry of Housing, Israel, $30,000, 1993

4. **Wiezel**, A.(90%), Beliveau,Y.,(10%), *Human Factors for Adoption of Real-Time Spatial Positioning with CAD-CAE,* Spatial Positioning Systems, Inc. Blacksburg, VA, $22,500, 1994
5. **Wiezel**, A., *Introduction of Cooperative Learning through an Electronic Course Management Tool,* Center for Innovation in Engineering Education, College of Engineering and Applied Sciences,and Del E. Webb School of Construction, Arizona State University, $7,382, 4/16/96-4/16/97
6. **Wiezel**, A., *Laboratory of Advanced Computing Applications in Construction,* Bechtel Corporation, $100,000, 10/10/96-10/10/97
7. **Wiezel,** A., *Development and Implementation of the Engineering Tutor Master Program,* Fluor Daniel, Inc., $40,000, 20/9/96-20/9/98
8. Schexnayder, C., **Wiezel**, A., *WWW Development Strategy for Construction Organizations*, ORCA 94-1087, $6,850, 5/97-5/99.
9. Schexnayder, C., **Wiezel**, A., *Electronic Aids & Collaborative Learning in Support of Knowledge Transfer,* Center for Innovation in Engineering Education, College of Engineering and Applied Sciences, $6,000, 4/16/97-4/16/98
10. **Wiezel, A**., "*Effects of Advanced Design tools (ADT) on Construction Productivity,*" Construction Research and Education for Advanced Technology Environments (CREATE), $52,285, 10/1998-5/2000
11. **Wiezel, A., "***Data Mining for Construction Project Parameters*," Markham Contractors Co., $20,485

COURSE DEVELOPMENT

New Courses

Introduction to Computing in Building Management (undergraduate level)
Robotics in Construction (graduate level)
Automation in Construction (graduate level)

Selected Subjects in Existing Courses

Computerized Methods in Construction Planning (graduate level) — CAD, Data Bases, System Integration, System Management
Construction Research Presentation (graduate level) — Multi-Media