

A Concept of Successful Collaborative Design towards Sustainability of Project Development

Yani Rahmawati, Nadjadji Anwar, Christiono Utomo

Abstract—Development in construction industry is leading to involve complexities in engineering systems; whereas it also required to its sustainability towards social, environmental, and economical aspects. Experts with requisite background and expertise are involved in order to integrate knowledge in achieving whole criteria through design process. Collaborative design is needed in order to attain optimum design through shared solution and goal from experts. This study is conducted to explore issues and approaches development of collaborative design research in construction and its influence to sustainability of the development. Literature review method is used in order to conceptually figure future research direction of collaborative design research. This research is a part of beginning process in doctoral research program, and will be used to support dissertation's conceptual definition.

Keywords—Collaborative design, multi-discipline design, design process, sustainability of project development.

I. INTRODUCTION

CONSTRUCTION industry is leading to involve multiple disciplines in completing the works where the emergence of complex problems in engineering system need to be solved [1]. It is not only has to consider building system itself, but also the impacts of building system to sustainability of built environment as a whole system [2], [3]. It is important to consider long-term environmental and economical benefits of urban growth and development to building design [4]. Experts with requisite backgrounds and expertise are involved in order to integrate knowledge in producing optimum design, which is deal with all criteria as a whole building systems. Conducting successful collaborative design is needed in order to assist the collaboration of experts in producing optimum solution as whole system design to achieve the sustainability project development of a building.

There are some definitions of collaborative design [5]-[9]. Collaborative design is an activity that requires participation of individuals in sharing knowledge and also organizing tasks and resources, especially on a large scale project, where design is produced by multiple experts whom work together at design process, in order to accomplish activities such as knowledge and data sharing, negotiation, decision making,

coordination, and managing design tasks [5]. Collaborative design is considered to design process where participants communicate and work together actively in order to define design goals and build shared design solutions [6]. Collaborative design is also defined as an arrangement of collaboration works for experts, in which it has capability to facilitate multiple perspectives or perceptions to work in same specific problems [7]. Collaborative design is an endeavor process of collective activity which consists of different teams with different competence and responsibility in similar design object [8]. The process of collaborative design is involving experts with multiple disciplines; Detienne [9] stated that there are two important processes in collaborative design; which are consisted of coordinating process in managing task interdependencies and negotiation mechanisms in managing integration of multiple perspectives.

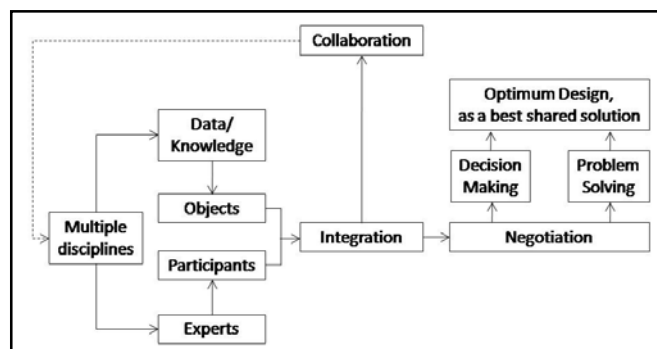


Fig. 1 Illustration of Collaborative Design Process (Adopted from: [5]-[9])

The process of collaborative design is illustrated on Fig. 1. Based on this illustration, it can be explained that main purpose in conducting successful collaborative design is to construct optimum design as an integrated solution from experts, which is complimentary to all criteria of building systems responsibilities towards built environment as a whole system. The objective can be realized through successful negotiation process in decision making and problem solving, in which it supports the integration process. Negotiation and decision making process are important in supporting successful collaborative design process [10].

There are two main factors of multiple disciplines that need to be integrated in collaboration; they are factors of design objects and factors of participants involved. Objects are consisted of data or knowledge that has been revealed from experts which need to be integrated in meeting all criteria of design; meanwhile participants consist of experts whom also

Yani Rahmawati is PhD Student in Construction Project Management, Department of Civil Engineering, Institut Teknologi Sepuluh Nopember, Surabaya - Indonesia (e-mail: yanirahmawati2012@gmail.com).

Nadjadji Anwar is a Professor of Water Resource Engineering and Management in Department of Civil Engineering at Institut Teknologi Sepuluh Nopember, Surabaya – Indonesia (e-mail: nadjadji@ce.its.ac.id).

Christiono Utomo is a Senior Lecturer in Department of Civil Engineering at Institut Teknologi Sepuluh Nopember, Surabaya – Indonesia (e-mail: christionoutomo@gmail.com).

need to be maintained in integration process with purpose to reveal best knowledge as a basic foundation of the design. The integration of building aesthetics, structures, utilities, and functions has to be fitted in order to maintain and take care environment and social surroundings by considering the construction process and the building impacts to sustainability of urban development [11]; it also has to give best and highest value to its function in attaining optimum revenue, which can support urban economics growth [12]. These criteria are needed to build a long term success of project development [13], which can be achieved through successful collaborative design process. Based from this purpose, it needs to recognize and understand issue and approach development that has been done in collaborative design.

This paper presents a literature review in collaborative design research. Review identifies issues and approaches development. Main issue in collaborative design research is conducting successful and effective collaborative design process with purpose to support sustainability in construction project development. Researches in collaborative design are synthesized by classifying them base on its issues and related approaches used. Each group is analyzed by comparing and combining issues appeared and approaches used in facing the problems. The result of each analysis is compiled to discover future research direction.

II. CONCEPTUAL BACKGROUND

Main reason in conducting collaborative design research is to generate and develop tools and systems, weather it is physically or conceptually, with purpose to support successful and effective collaborative design process. An achievement of successful collaborative design process can lead to sustainability of project development through the implementation of optimum design [14], [15]. It is important to know and recognize advantages and disadvantages of approaches that have been used in encountering the issues, where it can be applied as guidance to lead better collaborative design process.

Participants who are involved in collaborative design process have different backgrounds, disciplines, experiences, and geographic locations. Problems appeared related to conduct meeting and briefing between participants whom have to work together in design process. Each participant has different time and place availabilities, which caused un-efficient collaboration process and affected to problem solving and decision making in collaborative design process. Some research conducted to deal with this problem. Utomo et al. [16] conducted research mainly focused in inventing agreement options which can be applied in order to support evaluating and selecting alternatives to formulate solution in design process. Effective and successful collaboration works can be achieved through computer-based supported tools and systems, whereas participants are able to work in one area even though they are located in dispersed geographic place [17], [18]. Based from this important factor, researchers are inventing tools and systems based on information technology (IT) and communication infrastructure development to create space where participants are able to collaborate virtually [19].

Successful virtual collaboration project can be reached through implementation of information and communication technology in the process [20], [21].

Basic need of physically integrating participants was then developed in order to accomplish the need in integrating design process (as an object). This need is developed on the research by creating technically shared understanding between participants in virtual works environment [22]. By developing technical shared understanding in order to support successful collaborative design process, some research realized the need to consider social factors in collaboration process with main purpose to achieve best shared goal from the experts [23]. Related to this, some problems appeared based from social presence, which caused failure on goal and the process itself [24].

Based from issues and approaches development in collaborative design research, this literature study-based research conducted with main purpose to reveal issues and approaches which have been done in past to present research, and identify the future direction of approaches and possible issues that need to be done. As shown in Fig. 2, research with main topic of collaborative design is grouped and synthesized into three main groups which are based on three main issue developments in collaborative design. The groups consist of physical approach, technical approach, and social approach.

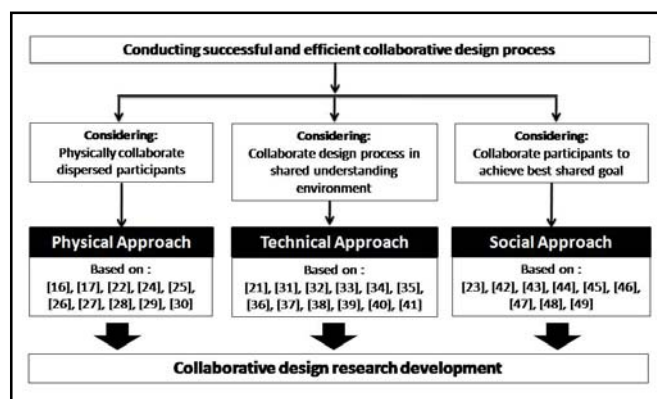


Fig. 2 Conceptual Figure of Literature Review Process

III. SYNTHESIZE AND ANALYZE

According to main issue development in collaborative design research, there are three categories of raised issues and approaches that have been applied. Collected published researches of collaborative design through past and present are synthesized based on each group and analyzed individually and generally to find conclusion of future research direction.

A. Physical Approaches

The first classification is physical approach, which contains of approaches that have been used in facilitating collaborative design process to face or avoid problems related to time and place availabilities of participants. In conducting collaborative design process, some participants are located in dispersed geographic place, which caused a problem in conducting meeting or briefing to solve problems and create decisions.

Based from this issue, research in the area of collaborative design is developed to invent tools or systems that able to facilitate collaboration works at same space where participants are located separately.

There are some literature review-based researches which conducted to explore approaches related to this problem. Based from review, it is found that collaborative works problems, which consist of group size and also time and place availability, can be eliminated or avoided using computer supported tools and systems [17]. In line with [17], Wang et al [18] found that internet and web application can be applied to support collaborative design process, especially in conceptual design process with the condition of participants in separated location. It can be concluded that IT development can be applied to resolve problems related to time and place availabilities of participants. Some research is conducted with case study-based research in order to explore descriptively the affectivity of tools and system in facilitating collaborative design process [23], [25], [26].

There is a case study-based research with focus on physical approach which explored descriptively through 3 case studies of supported tools that were used in collaborative designs; they are Electronic Cocktail Napkin, PHIDIAS Hypermedia System, and Construction Kit Builder; research found that there are some problems appeared by single used of supported tools, so the authors explored potential combination system, such as Hypersketch Prototype and Digital design sketchbooks and mobile [25]. Tools and systems were developed to the used of Virtual Design Studio (VDS) in facilitating collaboration at remote locations, through case study of collaborative design process which involved 3 participants from different countries, it was found that VDS can be used to facilitate collaboration works between dispersed participants, where participants involved able to work in one media, and it can be done at different time and place [23].

In line with [23], [26] conducted research mainly focus on single media that can be used to facilitate collaborative design between geographically dispersed participants. It explored descriptively through archival records, interviews, and direct observation on case mainly about the use of multi user workspace in facilitating collaborative design process. There were 3 projects that used as a case study, which consist of Maruyama Project, Ayuyagawa Project, and Mikata Project. It is found that there is a possibility to facilitate collaborative design process by using multi user workspace, where participants can work together in one media (workspace) with support systems and tools on recording design process and ability for different participants to edit the design object.

Another way in collaborating through separated location of participants is purposed by [27], who developed Hypermedia system in form of virtual discussion tables, which was able to be applied to facilitate activities in exposing knowledge or data from participants. Another system is purposed to facilitate the collaborative design process. Computer Aided Design (CAD) also has ability to facilitate the collaboration [28]. It is also able to support shared 3D workspace, where participants can work together to build and edit virtual 3D Model [29].

Meanwhile, model purposed by [30] where main purpose is to facilitate problems related to geographical location of participants and to facilitate mediation process by integrating Project Planning Process Model (PPPM) with web-enabled B2B facility, the integration can be used to build virtual workspace in order to manage participants with different time and place availability.

Based from the synthesis of physical approach-based research, it can be concluded that most of approaches were considered and focused on creating and inventing tools and system in form of single shared-media to support collaborative design process virtually, where it was made with main purpose to encounter time and place availabilities of participants in conducting meeting and briefing to produce design, especially in solving problems and making decisions. It is found that the facilities used are able to support geographically dispersed collaboration works. Communication in virtual is essential in obtaining right decision making [31].

B. Technical Approach

By using single shared-media of work as an effective approach in conducting collaborative design, participants and researchers were realizing the need to generate shared understanding environment between participants [23]. It is related to design object that has to be integrated in solving problems, especially in the process where participants work on limited space and cannot solve problems synchronously. Different backgrounds and expertise of participants also took part in the appearance of this problem [30]. Based on this, research then develop to generate shared understanding environment in collaborative design process with main purpose to achieve understanding of shared object between participants.

Creating shared understanding environment in collaborative design process is important, Saad and Maher [22] conducted literature study-based research with purpose to explore computer systems and tools which can be used to attain shared understanding between participants in conducting successful collaborative design process. Shared understanding can also be achieved or generated by managing inconsistent and ambiguous data received. Main purpose in conducting effective collaborative design process is to integrate data or knowledge which is revealed from experts. Data and knowledge can be managed in order to support negotiation process at collaborative design based on the appearance of inconsistency data problems during communication activities [32].

Knowledge or data management is important in conducting successful collaborative design [33]. It is important to manage data integration in problem solving and decision making process [34]. There are lots of systems and tools that are basically invented by using technical-based approach in generating shared understanding environment through data management. Some examples of systems purposed are design objects classification [35]; revealing information patterns by using data mining technique [36]; and building library to reduce semantic conflicts [37]. Data management is one of

technical-based approach in generating shared understanding environment between participants. Based from this approach, conceptual models which can be used to generate shared understanding in collaborative design process namely Shared Design Thinking Process Model are purposed [38]. In creating technical shared understanding environment, there is also need consideration to availability of editing process arrangement for participants involved in data integration process, which is important to support successful collaborative design process [39]. Related to these findings, Plume and Mitchel [40] conducted research in supporting collaborative design process through building information modeling of design object base on collaboration in shared building model, which can support the decision-making activities.

Shared understanding environment can also be reached by participants through understanding design flow and process completely. Each participants need to know histories of design and chronologies of problems solved. An exploratory research conducted by observing nine collaborative design processes, which were divided into three groups, and consisted of Face To Face (FTF); Computer Mediated Collaborative Design (CMCD) combined with teleconference communication; and CMCD with textual communication. Result found that the important thing in conducting successful collaborative design process is the textual record of the process [41].

Another exploratory case study-based collaborative design research was also conducted by using observation on three cases in order to define organization differences in arranging and managing task coordination in collaborative design process [42]. The organization consisted of coordination; cooperation; and collaboration. Result found that it is possible to integrate design project through VDS into asynchronous designing, and it needs social infrastructure through organization in order to attain best solution.

The issues and approaches development in collaborative design research was leading to the need of creating shared understanding environment in the process. At the beginning of research development, it built an effective way in conducting collaborative design process by solving problems related time and place availabilities through shared workspace. Then it was emerging to generate shared understanding environment through design process and design object integration by applying technical approach. This technical approach was able to facilitate and support technical shared understanding of design process, but research found that the technical approach can only integrates design process and design objects, it cannot support integration of participants [23], [42].

C. Social Approach

Based from synthesis and analysis of physical and technical approaches, it can be seen that there is a lack consideration in conducting collaborative design process through physical and technical approaches. Both approaches are mainly considered to physical process and design object, without considering the social factors in which the purpose is to achieve an integrated solution. From both approaches it can be found that physical approach can only be used to integrate participants but only on

terms of physical factor related to different time and place availabilities [23]; and technical approach can only be used to integrated design process technically, it cannot organize the social factors that can be considered in achieving best shared goal [42].

Effective collaborative design process can be conducted through good supported communication [43]. Social problems appeared basically caused by insufficient communication process between participants, in which these problems are influenced by designers' behaviors at design process [44]. Some technical communication facilities can also influence teamwork [45]. In order to deeply understanding the affect of social factors to successful collaborative design, a literature review with purpose to explore human related factors that need to be considered in conducting effective collaborative design process was purposed, research found that there are seven factors which consisted of contexts, supports, tasks, interaction processes, teams, individuals, and also overarching factors [46].

One of social factors that able to influence successful collaborative design process is teamwork. Some research found that integrated team design is able to support the successful collaborative design process [47]. It is also important to organize teamwork at the beginning to build integrated design team in achieving effective collaborative design process. Task coordination and its interdependencies can be considered in organizing and forming teamwork to support successful collaborative design process [48].

Another social factor that needs to be considered is in recognizing the social presence as causal factors for successful and effective collaboration process [24]. The research found that there is relation between social presence and task, and findings revealed that social presence influences the participants' attitude towards the task. Related to this found, participants' behaviors in decision making process are need to be concerned, because they are able to affect the outcomes of design process, where best integrated solutions cannot be reached [49]. Related to social factors concerned in supporting successful collaborative design, there is a need to consider social sustainability through collaboration skill, which consists of teamwork, compromise & negotiation process, cultural & social diversity, participation, and communication [50].

Generating shared understanding environment through social approach is needed. It is important to achieve best shared goal through decision making and problem solving of best knowledge that has been revealed from experts, it also can be used to facilitate the process effectively. It is known that social factors are also determining the successful and effective collaborative design process.

IV. RESULT AND DISCUSSION

The result of synthesis and analysis within collaborative design research is compiled and discussed as presented on Fig. 3. Based from result of synthesis and analysis process above, it can be seen that there are three main classifications or groups of collaborative design research; which consist of physical approach, technical approach, and social approach.

Those groups are classification of collaborative design research which is based on its issue development. Based on literature review above it is known that physical approach mostly invented shared workspace facilities; technical approach mostly created supported system and tools of technical shared understanding environment; and social approach mostly developed model and systems that supported socially shared understanding between participants.

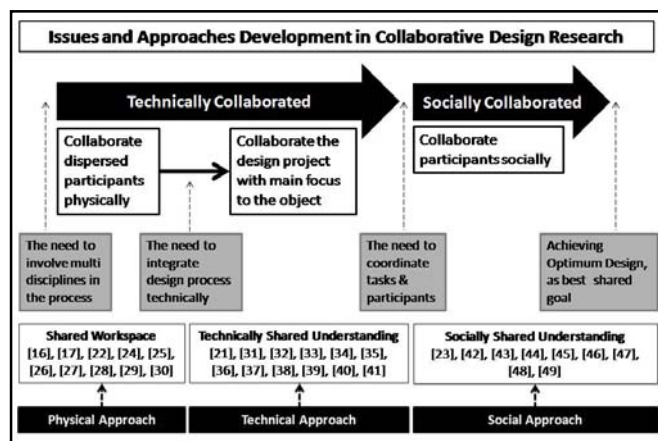


Fig. 3 Conceptual Figure of Literature Review Results

Most of invented methods, tools, or systems with physical-based approach were in the form of a shared-workspace [23], [25], [26], [29], [51]; which is a kind of single used media in facilitating collaboration works. It is made basically based on the need to integrate dispersed geographic participants. From the review, it is found that form of shared-workspace methods can be used to integrate participants from different locations and at different time. VDS is one kind of a shared workspace. It made participants able to work together without arising any kind problems related to time and place availabilities in conducting meeting or briefing to solve problems and make decision in design process. But some research found that shared workspace has some lack in supporting the successful collaborative design [41]. It might be possible to collaborate and integrate participants whom located at dispersed geographic to work together through one working media (workspace), but it has some difficulties in collaborating design process especially in integrating design objects. According to research conducted by [41], it is found that collaborative design is able to achieve success and run design process effectively as long as there is supported recording ability in the system, especially in textual model.

Issues were raised related to the need of integrating design process and design object technically. Main problems were related to the appearance of misunderstanding between participants, it was because of each participants did not know any objects or concept of design that had been given from other participants. A response is purposed in order to solve this problem, by inventing tools and systems that can integrate the data or knowledge in supporting shared understanding between participants [32]. The development of this invention was technically based, which was only considered to the

design object.

Some inventions which have been developed in the technical based approach were based on knowledge or data management [33]-[37], [40]. Main purpose of this approach is to manage data, which is revealed from experts with different expertise, it is used to achieve same perception between participants through management of ambiguous and inconsistency data received. The methods consisted of revealing data, building library to classify the meaning of each object and also storing data change. It can be concluded from researches categorized on this technical approach that shared understanding could be achieved as long as there is a storing facility that can be used to record design process, so that each participant able to track the design developments which were done by others, and this made participant able to understand every participants' thought.

Limited environment by virtual workspace through VDS caused lack of social interaction in collaborative design process. Even though there was endeavor in supporting the virtual work by using technical approach in achieving shared understanding environment between participants, some research found that VDS can only support the collaboration of design object, but it cannot integrate the participants [23], [42]. It is important to consider the social factor to build successful collaborative design [48], [52]; because it affects to the effectiveness of collaboration process which will lead to unsolved problems, insufficient design, and unfinished design process [24]. Based on this issue development, research was then grown and developed to consider social approach in supporting collaborative design process. The social approach consisted of teamwork management, communication, culture, organization, individual behavior, etc. There are some researches which consider in combining technical and social approaches in conducting successful collaborative design process [53], [54].

Research in the area of collaborative design is leading to consider the social approach in achieving the optimum design. It is not only can be used as a basic foundation to run the process effectively, but it is also able to support in revealing and integrating best solution from experts.

V. CONCLUSION

Based on literature review to collaborative design research, it is concluded that future direction research concerns to consider the social approach, which are focusing on managing the social presence with main purpose to reveal and collaborate best solutions from experts. Physical approach and technical approach is important and needed in conducting effective collaborative design process, but the most important factor is the social approach which can lead to achieve optimum building design that can support long-term function and the sustainable of project development itself through complimentary all criteria of environmental, economical and social aspects. This achievement will support a contribution of sustainable urban development.

REFERENCES

- [1] Liu, H., Tang, M., and Frazer, J.H., "Supporting Dynamic Management in a Multi-Agent Collaborative Design System", *Advance In Engineering Software*, vol. 35, pp. 493-502, 2004.
- [2] Utomo, C., Idrus, A., Isnanto, Nugraheni, A., and Rahmawati, F., "Negotiation Support for Value-based Decision in Construction", *Journal of World Academy of Science, Engineering and Technology*, vol. 60, pp. 1991-1997, 2011.
- [3] Stasinopoulos, P., Smith, M., Hargroves, K., dan Desha, C., *Whole System Design: An Integrated Approach To Sustainable Engineering*, London: Eartscan, 2009.
- [4] Wang, N., Chang, YC., and Nunn, C., "Lifecycle Assessment For Sustainable Design Options of a Commercial Building In Shanghai", *Building and Environment*, vol. 45, pp. 1415-1421, 2010.
- [5] Chiu, M.L., "An Organization View of Design Communication in Design Collaborative". *Design Studies*, vol. 23, pp. 187-210, 2002.
- [6] Zha, X.F., and Du, H., "Knowledge Intensive Collaborative Design Modelling and Support Part 1: Review Distributed Models and Framework", *Computers in Industry*, vol. 57, pp. 39-55, 2006.
- [7] Schmidt, K., "Models and Mechanism of Cooperative Work", *Risk National Laboratory Roskilde Denmark*, 1994.
- [8] Bucciarelli, L., "Between Thought and Object in Engineering Design", *Design Studies*, vol. 23, pp. 219-223, 2002.
- [9] Detienne, F., "Collaborative Design: Managing Task Interdependencies and Multiple Perspective", *Interacting With Computer*, vol. 18, pp. 1-20, 2006.
- [10] Utomo, C., and Idrus, A., "A concept toward negotiation support for value management on sustainable construction", *Journal of Sustainable Development*, vol. 4(6), pp. 56-66, 2011.
- [11] Ding, GKC., "Sustainable construction - the role of environmental assessment tools", *Journal of Environmental Management*, vol. 86, pp. 451-464, 2008.
- [12] Besley, T., and Ghatak, M., *Chapter 68 – Property Rights and Economic Development*, Handbook of development economics, vol. 5, pp. 4525-4595, Elsevier, 2010.
- [13] Heising, W., "The integration of ideation and project portfolio management – A key factor for sustainable success", *International Journal of Project Management*, vol 30 (5), pp. 582-595, 2012.
- [14] The Natural Edge Project, *Engineering Sustainable Solutions Program Technical Design Portfolio: Whole System Design Suite*, Australian Government: Department of the environment and water resources, 2007.
- [15] Melchert, L., "The Dutch Sustainable Building Policy: A Model For Developing Countries", *Building and Environment*, vol. 42, pp. 893-901, 2007.
- [16] Utomo, C., Idrus, A., Napiyah, M., and Khamidi, MF., "Agreement Options on Multi Criteria Group Decision and Negotiation", *International Journal of Computational and Mathematical Science*, vol. 3(5), pp. 203-207, 2009.
- [17] Kvan, T., "Collaborative Design: What Is It?", *Automation in Construction*, vol. 9, pp. 409-415, 2000.
- [18] Wang, L., Shen, W., Xie, H., Neelamkavil, J., and Pardasani, A., "Collaborative Conceptual Design - State Of The Art And Future Trends", *Computer-Aided Design*, vol. 34, pp. 981-996, 2002.
- [19] Utomo, C., Idrus, A., Napiyah, M., and Khamidi, MF., "Agreement Options in Multi-person Decision on Optimizing High-Risk Building Columns", *International Journal of Computer, Information, and System Science, and Engineering*, vol. 3(2), pp. 97-104, 2009.
- [20] Oztok, M., and Ordener, N., "Information and Communication Technologies in Collaboration Projects Via The Internet", *International Journal of Social and Human Sciences*, vol. 1, pp. 195-200, 2007.
- [21] Ha, JK., and Kim, YH., "An Exploration on On-Line Mass Collaboration: Focusing on Its Motivation Structure", *International Journal of Social and Human Sciences*, vol. 2, pp. 307-312, 2008.
- [22] Saad, M., and Maher, ML., "Shared Understanding in Computer-Supported Collaborative Design", *Computer Aided Design*, vol. 28(3), pp. 183-192, 1995.
- [23] Kolarevic, B., Schmitt, G., Hirschberg, U., and Kurmann, D., "An Experiment in Design Collaboration". *Automation in Construction*, vol. 9, pp. 73-81, 2000.
- [24] Weinel, M., Bannert, M., Zumbach, J., Hoppe, HU., and Malzahn, N., "A Closer Look on Social Presence as a Causing Factor in Computer-Mediated Collaboration", *Computers In Human Behavior*, vol. 27, pp. 513-521, 2011.
- [25] Gross, MD., et al., "Collaboration and Coordination in Architectural Design: Approaches to Computer Mediated Teamwork", *Automation in Construction*, vol. 7, pp. 465-473, 1998.
- [26] Woo, S., Lee, E., and Sasada, T., "The Multiuser Workspace as The Medium for Communication in Collaborative Design", *Automation in Construction*, vol. 10, pp. 303-308, 2001.
- [27] Lee, Y.C., and Gilleard, J.D., "Collaborative Design: A Process Model for Refurbishment", *Automation in Construction*, vol. 11, pp. 535-544, 2002.
- [28] Li, WD., Lu, WF., Fuh, JYH., and Wong, YS., "Collaborative Computer Aided Design – Research and Development Status", *Computer Aided Design*, vol. 37, pp. 931-940, 2005.
- [29] Nam, TJ., and Wright, D., "The development and evaluation of Syco3D: a real-time collaborative 3D CAD system", *design studies*, vol. 22, pp. 557-582, 2001.
- [30] Verheij, H., and Augenbroe, G., "Collaborative Planning of AEC Projects and Partnership", *Automation In Construction*, vol. 15, pp. 428-437, 2006.
- [31] Altinoz, M., "An Overall Approach to The Communication of Organizations in Conventional and Virtual Offices", *International Journal of Social and Human Sciences*, vol. 2, pp. 365-371, 2008.
- [32] Lottaz, C., Smith, IFC., Nicoud, YR., and Faltings, BV., "Constraint-Based Support for Negotiation in Collaborative Design", *Artificial Intelligent in Engineering*, vol. 14, pp. 261-280, 2000.
- [33] Dave, B., and Koskela, L., "Collaborative Knowledge Management - A Construction Case Study", *Automation in Construction*, vol. 18, pp. 894-902, 2009.
- [34] Veeramani, D., Tseng, HP., and Russel, JS., "Computer-Integrated Collaborative Design and Operation in The Construction Industry", *Automation in Construction*, vol. 7, pp. 485-492, 1998.
- [35] Huifen, W., Youliang, Z., Jian, C., Lee, S-F., and Kwong, W-C., "Feature-Based Collaborative Design", *Materials Processing Technology*, 139, 613-618, 2003.
- [36] Chiu, ML., and Lan, JH., "Information and In-Formation, Information Mining for Supporting Collaborative Design", *Automation in Construction*, vol. 14, pp. 197-205, 2005.
- [37] Gu, N., Xu, J., Wu, X., Yang, J., and Ye, W., "Ontology Based Semantic Conflicts Resolution In Collaborative Editing Of Design Documents", *Advanced Engineering Informatics*, vol. 19, pp. 103-111, 2005.
- [38] Du, J., Jing, S., and Liu, J., "Creating Shared Design Thinking Process for Collaborative Design", *Network And Applications*, 2011.
- [39] Leeuwen, JPV., and Fridqvist, S., "An Information Model For Collaboration In The Construction Industry", *Computers in Industry*, vol. 57, pp. 809-816, 2006.
- [40] Plume, J., and Mitchell, J., Collaborative Design Using a Shared IFC Building Model—Learning From Experience", *Automation in Construction*, vol. 16, pp. 28-36, 2007.
- [41] Gabriel, GC., and Maher, ML., 2002 "Coding and Modelling Communication in Architectural Collaborative Design", *Automation In Construction*, vol. 11, pp. 199-211, 2002.
- [42] Lahti, H., Hakkarainen, PS., and Hakkarainen, K., "Collaboration Patterns in Computer Supported Collaborative Designing". *Design Studies*, vol. 25, pp. 351-371, 2004.
- [43] Lin, C., Standing, C., and Liu, Y.C., "A Model to Develop Effective Virtual Teams", *Decision Support Systems*, vol. 45, pp. 1031-1045, 2008.
- [44] Peng, C., "Exploring Communication in Collaborative Design: Co-Operative Architectural Modelling". *Design Studies*, vol. 15 (1), pp. 19-44, 1994.
- [45] Cheng, NY, "Review: Approaches to Design Collaboration Research", *Automation in Construction*, vol. 12, pp. 715-723, 2003.
- [46] Patel, H., Pettitt, M., and Wilson, JR., "Factors of Collaborative Working: a Framework for a Collaboration Model", *Applied Ergonomics*, vol. 43, pp. 1-26, 2012.
- [47] Ping, CS., Keung, CNY., and Ramanathan, M., "Integrated Team Design Process – Successful Stories of Hong Kong MTR Corporation Projects", *Procedia Engineering*, vol. 14, pp. 1190-1196, 2011.
- [48] Rahmawati, Y., Utomo, C., and Anwar, N., "Exploring Socio-Technical Factors to Successful Collaborative Design in Product Development: A Review (Accepted for publication)", *International Conference of Organization Innovation*, to be published on July 10-12, 2012.
- [49] Vivacqua, AS., Garcia, ACB., and Gomes, A., "BOO : Behavior-Oriented Ontology to Describe Participant Dynamic in Collocated Design Meetings", *Expert System With Application*, vol. 38, pp. 1139-1147, 2011.

- [50] McMahon, M., and Bhamra, T., "'Design Beyond Borders': International Collaborative Projects as a Mechanism to Integrate Social Sustainability into Student Design Practice", *Cleaner Production*, vol. 23, pp. 86-95, 2012.
- [51] Kamel, "A Unified Characterisation for Shared Multimedia CSCW Workspace Designs", *Information and Software Technology*, vol. 41, pp. 1-14, 1999.
- [52] Rahmawati, Y., Utomo, C., and Anwar, N., "Collaborative Design in Construction: Past, Present, and Future Research (Accepted for publication)", *International Conference of Sustainable Built Environment*, to be published on July 10-12, 2012.
- [53] Lu, SCY., Cai, J., Burkett, W., and Udwardia, F., "A Methodology for Collaborative Design Process and Conflict Analysis", *Annals Of The CIRP*, vol. 49(1), pp. 69-73, 2000.
- [54] Lu, SCY., Elmaraghy, W., Schuh, G., and Wilhelm, R., "A Scientific Foundation of Collaborative Engineering", *Annals of the CIRP*, vol. 56 (2), pp. 605-634, 2007.

Yani Rahmawati received her bachelor degree in Architecture and master degree in Construction Project Management. She is taking doctoral degree in Construction Project Management, Institut Teknologi Sepuluh Nopember (ITS) Indonesia. Her dissertation's research topic is collaborative design.

Nadjadi Anwar received his bachelor degree in Civil Engineering at Institut Teknologi Bandung (1979) and master degree in Civil Engineering as at Colorado State University (1982). He took doctoral degree in Civil and Environmental Engineering at Toyo University (1998). He is a Professor of Water Resource Engineering and Management in Institut Teknologi Sepuluh Nopember (ITS) Indonesia. His research interests are water resource engineering and management, asset management, and construction management and operation research.

Christiono Utomo received his bachelor degree in Architecture (Quantitative Method in Design Decision), and master degree in Project Management (Decision Science). He took doctoral degree in Economics and in Civil Engineering. He is a Senior Lecturer and Researcher at the school of Construction Management, Institut Teknologi Sepuluh Nopember (ITS) Indonesia. His research interests are value engineering and management, group decision and negotiation support, and corporate real estate.