**BIM IN ACADEMIA**

Shifting our attention from product to process

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**ABSTRACT:** This paper proposes changes in architectural education to respond to BIM technology and the resulting complexity in the design concept. We examine the interoperability issues between design and analysis in professional practice. We present the results of a case study mapping the activities of two interdisciplinary student teams in the early design phases of a BIM-enabled project. Results show the problems associated with building simulation tools, core knowledge lacking in architectural education, and the relationship between information management, team process, and the types of tools used. A flexible curricular structure is proposed in architectural education, expanding our professional roles.

**KEYWORDS:** BIM, Architectural education, multidisciplinary design


**MOTS-CLÉS :** BIM, éducation architecturale, design multidisciplinaire

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1. INTRODUCTION

Is architecture a multi-headed discipline or a new single identity? In academia, any changes to address current trends in practice must also address a broader vision for the architecture profession. We contend that because architecture is taught as a single discipline, it fails to provide students with a clear understanding of the professional options available to them. Due to demands for buildings to meet sustainability goals, pressures to formalize design analysis and evaluation throughout the building lifecycle have increased. On the demand side, there is a renewed need for reducing energy consumption in buildings and improving overall environmental performance. On the supply side, the building industry is adopting building information modelling (BIM) technology to facilitate the design, analysis, construction, and operation of buildings. Therefore, the professional role of the architect is expanding, and so must her level of expertise, in order to meet these challenges.

Eastman et al. (2008) suggest that BIM technology not only deals with the integration of various types of computer tools for project authoring, evaluation, and planning, but also with the method of integration of various domain expertise earlier in the design process. The concept of integrated practice has emerged from the introduction of BIM technology in the AEC industry. This active collaboration of domain experts, results in more information being managed during the early project phases, as the designer begins to formulate a design solution. In addition, building requirements place emphasis on sustainability and overall improved building performance. In architectural institutions there are on-going efforts to revise curricula in response to these changes in practice (Loftness et al. 2005). Therefore the goal to include BIM in architectural education brings with it the need to review two other components: professional practice and building technology.

This paper proposes a new curricular framework to respond to developments in BIM, integrated practice (IP), and building technology (BT). We examine the interoperability issues between design and analysis domains. The use of simulation technology for building evaluation and the resulting complexity in the early design phases are discussed. We present the results of a case study mapping the activities of two interdisciplinary student teams during the early design phases of a BIM-enabled project. Results describe the relationship between team process, the tools being used, and the management of project information. By exploring the problems associated with simulation tools, areas of knowledge lacking in architectural education are identified. A curricular structure is proposed to include “threads” of knowledge missing in architectural education. In this new paradigm, the education of the architect ceases to be a fixed set of skills and knowledge, opening up to new professional roles.
2. BIM, IP, AND BT IN PROFESSIONAL TEAM INTERACTIONS

Building information modelling is rooted in the concept that all the data associated with a building model could be held in one repository. With this technology, the goal is to facilitate the exchanges between various domains in the AEC industry, by having a centralized data model accessible to various domain applications. This is particularly relevant as the industry strives to optimize the design process. By increasing analysis and evaluation of design, earlier in the process, the goal is to reduce the cost and waste that occur with changes in the later phases of any project (Fallon and Palmer 2007).

Developments in interoperability have evolved from data mapping between the building information model and application tools, to structuring the process of information exchange among domains. In this context, three interoperability issues have been identified. Different subsets of data, or views, are needed by different domain applications. Various domain models may exist at the same time, and therefore, the central data repository needs to be managed to verify the correct version of the data. The overall data exchange process also needs to be managed to ensure the complete set of data is available to each domain application. In essence, because of the ever-changing nature of the building information model, interoperability can only be facilitated if the data exchanges and structured and predefined.

2.1. Tool interoperability between design and analysis domains

Two types of tools are associated with BIM, tools that integrate multiple domain functionalities for design and analysis, and interoperable tools, provided in a “suite” such as Autodesk’s Revit Architecture for architectural design, Revit MEP for mechanical engineering design, and Green Building Studio, a web-based simulation tool for environmental analysis. These tools are meant to facilitate the ability for the designer to evaluate the design model. From the domain of analysis and building simulation, these “designer-friendly” tools tend to simplify the complexity of the problem to be evaluated.

Malkawi and Augenbroe (2003) describe a shift from “designer-friendly” to “design-integrated” tools. In this approach, variations in the structuring of design teams are based on degrees of integration, in terms of interoperability and the information exchange between designers and building simulation experts. In addition, a greater flexibility in team interactions is produced by the increasing use of building simulations in web-hosted simulation services, real time building simulation, and performance requirement driven simulations. These manifestations also create a demand for deeper knowledge of complex computational processes.
2.2. Meaningful feedback in an interdisciplinary dialog

The interoperability of design teams sharing information through “design-integrated” tools implies that information flows both ways between the design and analysis domains. De Wit (2004) argues that communicating the uncertainties in building simulation to the designer or decision-maker is more appropriate than comparing a set of aggregated results to a benchmark value. Because of the dynamic nature of the design model, it is necessary to communicate the possible range of “performance values against the probability of their occurrence”.

The use of building simulation as a mode of design assessment reveals that more research is needed to provide meaningful feedback to the design domain due to the difficulties found in dealing with numerical data input and output. On the design side, Bleil de Souza and Knight (2007) suggest that current efforts in managing and post-processing numerical data are still difficult to interpret practically, because concepts of performance and systems thinking are not well understood by architects. They propose a framework to put the core concepts of building simulation in architectural terms, providing a common language to incorporate “an integrated dynamic system approach”. Authors conclude that architects need a greater knowledge of building technology in order to understand building physics and the interrelationships of functions and building components. Once architects are equipped with this knowledge, they will be able to make substantive design changes to improve building performance.

2.3. Emergence of new types of expertise

Despite efforts to improve interoperability and provide meaningful results to improve design team communication, we find that the shift in emphasis from data mapping to process modelling, is a shift from preconditioned scenarios to preconditioned cultural roles. We believe that changes in practice are reframing of our professional roles, requiring both, the ability for the various domains in the AEC industry to “inter-operate”, and the expansion of the skill set of architects to improve the dialogue. In a related study, Sanguinetti and Abdelmohsen (2008) propose a model of BIM expertise where the design and analysis domains are coupled throughout the restructured phases of a project. The coupling of design and analysis implies that both domains are of equal importance in the team. In this model the process alternates between analysis and design in the following project tasks: Describe, Propose, Evaluate, Assemble-3D, Assemble-4D, and Re-evaluate. Each task is decomposed into sub-tasks in two levels: domain knowledge and tool knowledge. The sequencing of those sub-tasks denotes expertise at the tool and domain level.

Another important challenge also needs to be considered as the promise of BIM comes into fruition: the increasing complexity of our models. It is
generally understood that buildings are complex systems composed of interrelated subsystems. These subsystems need to be designed and evaluated using various domain criteria. We propose that current trends in team interaction point to a different approach to the definition of our professional roles, where the design and analysis domains become integrated and expand into different specializations with their own evaluation criteria and that it is these emerging areas of design/analysis that then must interoperate.

What emerges is a new mode of interaction, beyond the concept of a dialogue between separate domains, where all members are design participants that can provide different assessments of the project. In this context, design becomes a collective activity. Project information and domain knowledge are shared, created, and utilized. Team members connect to others in the shared context of the architecture team, and their individual knowledge is shared so that new knowledge is created.

The core concept of an integrated practice is indeed a collaborative participation where all contribute in the design and evaluation of the project. In its inception, the goal of BIM technology was to achieve this level of interoperability through a universal data model for the entire AEC industry. However, current developments in design and analysis domains tools demonstrate that, because of the heterogeneous and dynamic nature of design data, interoperability at the application level remains a hurdle. Research in the analysis domain has shown that focusing on both the process of team interaction and subsets of data can enhance communication (Augenbroe et al. 2003). We propose that another shift at the level of our professional roles must also take place. As the professional demands on architects increase, specializations in integrated areas of design and analysis must be established.

3. CASE STUDY OF A MULTIDISCIPLINARY STUDENT TEAM INTERACTION

In order to test our hypothesis, we conduct a case study to compare the interactions of two interdisciplinary teams participating in Stanford University’s AEC web-based course. This course offers an interesting model of interdisciplinary design based on professional interactions found in practice. This course has been running for 15 years, teaming students from 3 domains, architecture, structural engineering, and construction management, to work together and solve a design problem in a distributed setting (Fruchter et al. 1996).

In our case-study, a fourth domain is introduced: building technology. In Team A, one student is tasked with being both the designer and the building technologist, and in Team B, two building technology students are added to the traditional AEC team. The objective of the study is to compare team interactions where expertise in design and analysis is integrated (Team A) and where it remains separate (Team B). The goal is to identify pedagogical strategies
toward the integration of BIM, and associated areas of knowledge: integrated practice and building technology.

The AEC web-based project is organized in two phases: concept development and preliminary design development. The project task is to design an educational facility in an existing university campus. Each team is given a different site with complex contextual issues ranging from climate, soil, access roads, etc. The functional program is provided as a list of area requirements and an adjacency matrix. Other requirements include maximum building height, budget, maximum building area, and a restriction of three possible geometric footprints. In the first phase, students have an initial meeting where teams work on a two-day “design-charrette” to formulate preliminary ideas for the project. In this first interaction, students become aware of the needs of the other team members and develop a set of project tasks to be discussed in future web-based meetings. The final requirements for this phase are two architectural proposals for the site, and for each proposal, two engineering alternatives, one in concrete, and one in steel. In the subsequent phase, one proposal is selected for development, and a LEED silver rating is required.

The course has been structured to facilitate web-communications, using commercially available teleconferencing tools, an ftp site, and other knowledge-capture tools provided by Stanford University. Team meetings are scheduled using a weekly agenda, and members are to take turns in the role of meeting facilitator or scribe. The goal is to enable each student to be a leader and to understand the needs of the other domain disciplines. All the meetings are also attended by the course instructor, and occasionally by former students playing the role of project owners. As part of the case study, all team meeting are documented tracking the process and progress of the team. An interview is also conducted at the end of the course.

4. OBSERVING INTERDISCIPLINARY TEAM WORKFLOWS

4.1. Team process

We find that the highly structured nature of the course perpetuates preconceptions and biases in the cultural roles of architects and engineers. In both teams, interactions remained sequential, and always initiated by the architect.

In Team A, this creates a lot of pressure on the architect to lead the team, coordinate meetings, and integrate the different domain models. Because some team members lacked 3D modelling skills, the architect/building technologist devotes a lot of time rebuilding models that would integrate all the concerns of the team. In addition this student spends a lot of time to provide two architectural solutions in the first phase as required in the syllabus.
In Team B, there are also misconceptions in the role and tasks to be performed by the building technologist. Team expectations are that the building technologist is simply to provide information on the layout of the HVAC ductwork, and size of the mechanical room and equipment. The suggestions for design revisions given by the BT students after an analysis of the sun exposure of the building are considered premature. In addition, the project progress is temporarily stopped in two occasions, when the architect is ill for a week, and due to other scheduling conflicts. As a result, Team B has only one complete solution and a hand-sketch for the second architectural solution in the first phase.

4.2. Information management

It is very difficult for teams to deal effectively with the low interoperability among some tools, as each team-member applies her discipline knowledge, using her preferred tools for project development. The result is a lot of time spent to retrieve the data lost.

In Team A, the architect/building technologist takes on the responsibility of managing and integrating all the models from other domains. She also has to interoperate between Revit and another geometric modelling tool to develop the more complex geometrical forms in her design. A large portion of the data from other platforms does not import into Revit. To perform the design analysis, she uses Design Builder and recreates the two options for the design model in this tool. For the evaluations in the second phase, she runs out of time and cannot reconstruct the models again, so she uses eQUEST for the energy simulations. We find that in Team A simulation tools are used for evaluations after the fact, and not to aid in decision-making during the design process. Changes in the design features, to reduce energy consumption or improve natural ventilation, are done following the feedback provided by industry mentors participating in project reviews.

The building technologists in Team B use a large variety of tools; they also systematically explore a wider range of solutions to improve the energy performance of the building. One of the students uses Ecotect to evaluate climatic conditions such as sun exposure and wind direction. Because the architect in the team only uses SketchUp, the building technologists have to recreate the design model in various tools: Ecotect, Design Builder, and Revit MEP, and eQUEST. The BT students find that the other members of the team do not understand the graphs representing quantitative results. This type of miscommunication occurs a few times during the process, and the BT students take time to communicate graphically and verbally the information to other team members. Pictures rather than graphs prove to be a more effective tool for team communication. We find that Team B is able to do analysis followed by the
implementation of design revisions. Although this team experiences similar difficulties with tool interoperability, these problems are overcome because the team has a great interpersonal communication. Team meetings have a detailed agenda where all members report on their efforts. Team discussions are conducted at length to solve project issues. A natural team leader emerges in this group, one of the structural engineers, who is trusted by the team, and keeps a good project pace. In addition, because the team had 2 building technologists, a lot more development is achieved toward sustainable design. We find that the BT students also kept a good communication with the industry mentors outside of project reviews in order to develop the technical solutions.

4.3. Performance goals

Although the course has an incentive of a prize for the team that best utilizes sustainable or green construction techniques; the project lacks the proper definition of performance goals. It is up to the individual student or team to bring up these concerns in the first phase of the project. In the second phase, the LEED rating is simply used as a check-list to achieve the proper rating.

In her dual role as designer and building technologist, the student in Team A has to balance the course requirements to provide an overall building concept in terms of form and functional layout, and the tasks to translate the project needs into performance criteria. In order to manage these two project views, the student concentrates on architectural design and identifies two specific building technology concerns: providing natural ventilation, and reducing energy consumption. These functional requirements are then matched with two features in the building: a) an atrium to bring natural light and promote natural ventilation, combined with a distribution of perimeter spaces to take advantage of wind directions; and b) the utilization of wind turbines on the building roof to harvest wind energy.

After some initial education of the other members in Team B, the collaboration with the BT students is very beneficial to the project. The two building technologists provide valuable information on climate and sun exposure in the first phase. The students also run simulations to evaluate the performance of some design features such as roof courtyards and shading devices and the design is coordinated to maximize their efficiency. In the second phase, they develop a sophisticated design to reduce energy consumption, including a ground source heat pump, photovoltaic panels on the roof, stationary external shading in the windows, an under-floor air delivery system on the ground floor, and a displacement ventilation system in the other two floors of the building. The team is given the award for the best sustainable design at the end of the course.
5. PEDAGOGICAL IMPLICATIONS OF INTERDISCIPLINARY COLLABORATION

The outcomes of this case-study show that interdisciplinary courses offer a great opportunity for students to familiarize themselves with the kinds of interactions that go on in professional practice. However many interoperability issues are encountered. Previous studies in activities of interdisciplinary design teams, point to the problems of communication and team workflow (Fructher et al. 1996, Austin et al. 2001). Each discipline in the team has a separate model, which is in essence a subset or view of the project. Each domain has its own terms and language to represent and describe the design. Finally, each domain has a different medium or tool for representing and exchanging information. These studies suggest team design process can also be improved by managing phasing and iteration. Based on the results of this case study, we conclude that more support is to be provided to the students in these types of courses, in order to achieve the goal to prepare students for the challenges of integrated practice and sustainable design, and maximize the use of BIM technology.

5.1. Interoperability framework

In general, students should be given more support in content creation and data modelling. This can be done by pre-structuring the process or doing research. In the first option, teams agree on certain applications in order to expedite the exchange of project information and references such as DOE’s manual of best practices is used to set design guidelines. Tools like Equest and WeatherTool may be the most appropriate software for the first phase in order to understand context and microclimate, and aid decisions such as building orientation, percentage glazing, thermal mass, ventilation system, and renewable energy strategies. Simulation results at this early stage can be useful only if there are benchmarks for analytical comparison. In the second option, professional mentors involved in innovative practices provide preliminary instruction on interoperability and modelling practices for better data exchange. Teams are asked to do research or case studies as part of the 2Day charette for an assessment of green features and sustainable alternatives.

5.2. Studio culture and collective knowledge creation

Web-based communications and on-line communities are now commonplace, with tools like Skype and sites like Facebook. It may be more of a challenge to achieve this level of connectivity among practitioners where good process can be a professional asset and therefore can be a valuable part of professional services. In order to overcome the biases that separate our disciplines, an interdisciplinary courses need to provide spaces for freely exchanging different
points of view. This is highly difficult when all communications are monitored by the instructor. Beyond structured team-building activities, spaces for sharing ideas and promoting more collaborative processes must be encouraged. We find that this is a key aspect of “studio culture” which is missing in this model of interdisciplinary collaboration.

5.3. Emergence of the interdisciplinary studio

Although the pedagogical model of the interdisciplinary web-based course has great potential to provide students knowledge in the areas of BIM, BT, and IP, the structure of the course breaks down due to biases in domain roles that hinder team interaction, loss of data due to low interoperability, and lack of performance goals in the project definition. In general, team process is constrained by these problems to a degree that hinders innovative solutions. We find that conservative approaches to design problem-solving are encouraged under the guise of being “realistic”. We believe that these problems can be overcome by keeping strong ties with innovative practices, providing a robust framework for interoperability to support the complex interactions of the team, and promoting studio culture, as a place of innovation and growth.

We believe that different architecture schools can generate a variety of interdisciplinary studios, where the projects are tailored based on the different programs housed in the school. Students should be encouraged to take more than one of these courses in order to build upon them, and develop the skills expected of our future professionals. Only then, students will be empowered to handle the demands of integrated practice, customized project delivery, and sustainable design.

6. RESTRUCTURING ARCHITECTURAL EDUCATION

When approaching technology, it seems that most architecture schools have focused on new courses to teach how to use tools rather than core concepts. It has been argued that for architecture graduates to be able to design buildings that meet BIM and BT demands, their palette of tools should cover a wider spectrum, including performance simulation tools and planning tools for cost estimation and other purposes (Lofness et al. 2008). This is more evident when dealing with BIM technology in general and the current rush “teach Revit” including the debate whether BIM tools should be included in design studio or it should be a separate course. When it comes to building technology, the choice of simulation tool is not so obvious. Soebarto (2005) reports on problems found in teaching building simulation to architecture students at the master’s level. Even when using “designer-friendly tools”, students did not understand the types of input required for a simulation or load calculation,
much less how to interpret the simulation results. Students lacked fundamental knowledge of the concepts of building heat transfer or thermal properties of materials. She found that students relied on default values without understanding the meaning of certain concepts such as infiltration. She also describes the difficulty the students have with the simulation tool’s interface, specifically when they had to search for values not found in the tool’s library. Many students were overwhelmed when dealing with numerical data. In essence, foundational knowledge needs to be provided for students to properly use simulation tools for design analysis.

Architectural faculty and practitioners have provided insights into other aspects to be considered, as architectural curricula responds to changes in the profession (Strong 2007). Emphasis should be placed on teaching core concepts rather than specific tool functionalities (Guidera 2006; Ibrahim 2004). The introduction of BIM in academia cannot be done by including a single new BIM course, because BIM, IP, and BT, are interrelated. We suggest content revisions to the academic curriculum must happen at two levels: courses to expand foundational knowledge to support the level of expertise needed in practice, and interdisciplinary design studios, or other types of problem-based courses, to introduce students to the core concepts of BIM, BT, and IP. We propose a flexible curricular structure to incorporate all these changes and expand our professional roles.

6.1. Core concepts

BIM technology enables the representation of heterogeneous types of information involved in the design of a building. The data model components are “intelligent digital representations” of the building, for measurement, analysis, and exchange of project-related information. (Eastman et al. 2008). Ibrahim identifies two core concepts of BIM: content creation and data modelling. He proposes that BIM could be introduced to architecture students in three steps. First introduce the students to modelling concepts similar to that of a CAD application, then advanced parametric modelling including customization using programming. The final step includes other aspects of data modelling and interoperability, such as creating of property sets and structuring the information to be shared with other domains.

Cheng proposes that the teaching of building information modelling should permeate throughout the curriculum, enhancing the architect’s communication skills and leadership role needed in an integrated practice, and keeping focus on design-centered pedagogy. “While design remains central, critically important for studio and other courses are the ability to work successfully in interdisciplinary creative teams” (Cheng 2006). The concept of IP describes the kind of interdisciplinary collaboration where all team-members participate throughout the
project phases, in a BIM-enabled environment, to facilitate and optimize project delivery. Core concepts of IP focus on the exchange of information among project stakeholders: team-building, project planning, communication, risk-management, and implementation (Elvin 2007). In addition to the fundamental of coordinating and managing projects, we should also examine the evolution of our fee structure.

Loftness et al. (2005) suggest that architecture and architectural engineering departments should have a closer integration between design and systems thinking, in addition to providing a base in building physics and traditional building technology courses. Authors identify building performance as the core concept for teaching building technology. This approach to teaching building technology emphasizes the consideration of performance multi-criteria, and promotes innovation in the design and integration of building systems, and “multidisciplinary design processes” to achieve sustainability goals. Authors propose that architecture graduates should have competency in the analysis of performance data, and knowledge of analysis tools for energy performance, lighting simulation, and computational fluid dynamics.

6.2. Foundational courses

We believe that core concepts of BIM, BT and IP are to be delivered throughout many courses; but, to develop the skills needed to deal with technological changes in architectural practice we must also review the foundational courses to strengthen core knowledge and support our use of tools. Most architectural schools in the United States have a larger offering of courses in history and theory than in building technology. Expanding the number of courses in this area cannot be resolved by teaching tools, which is in essence teaching process with limited knowledge content. For example, concrete knowledge of relevant subject matter such as the laws of thermodynamics and principles of heat transfer, is needed to support critical thinking skills to analyse outcomes of a building simulation. Courses in the following areas must expand:

- **Computation**, to introduce students to concepts of computational modelling and simulation, object oriented programming (representing data structures), and web communication
- **Building physics**, to expand the knowledge base of our students the principle of environmental design, and building behavior, and the physical properties of materials
- **Advanced mathematics**, to support geometric modelling, data analysis, and other numerical methods
- **Systems thinking and building systems integration**, to expose students to complexities in buildings systems, building performance concept and performance specification, and applicability of sustainability goals
Whether all foundational courses are taught in within the school should be determined locally. For example, it could be argued that a general course in thermodynamics is too broad for architecture students, and it would be better to focus on phenomena pertaining to built environments. However this puts demands for teaching resources that may not be available.

6.3. Flexible curricular structure

As the complexity of our professional interactions, and the subsequent technological requirements increase, we re-examine academic curricular structure. We believe that the current trends in practice reveal that architectural education needs to provide lines of specialization as professional options. We propose that simulation expertise can become an area of specialization for architects, as one of many roles an architect could undertake in practice, such as project management, and construction administration.

We propose a new curricular structure inspired by two academic models. The education of medical professionals is structured to introduce students to complex systems and the different areas of specialization in their field. In the first two years of their education, students are introduced to the different systems of the body and the functioning of these systems at various scales. The next two years, students “rotate” to be exposed to major areas of specialty. In these rotations, students learn about the problems with systems and ways to solve them. At this time they can opt for an area of specialization or decide to be general practitioners. A new model providing flexibility in defining professional specialization and expert knowledge is found in the Threads program for computer science at Georgia Institute of Technology. Curricular content is organized in eight different skill sets that students can combine in 28 ways to customize their education. The curriculum can be enhanced further according to four professional roles ranging from master practitioner to innovator.

Similarly, architectural education could be restructured into lines of specialized knowledge that can be customized by the student to pursue an area of specialty and a role in the profession. This approach to architectural education breaks through stagnant dichotomies splitting architecture into science and art, building and architecture, etc. We believe the kinds of knowledge needed for future architectural professionals cannot be simply added to the current curricular structure. Changes in architectural pedagogy must include flexibility in the skill set of architects, enabling paths toward different areas of specialization including designer and simulationist.
7. CONCLUSION

An exploration of the issues related to a tool-approach to teaching technology reveals that architects lack foundational knowledge required to use effectively BIM tools for design and simulation tools for analysis. To achieve expertise in the professional roles available to architects, a broad revision of architectural education is presented. We propose regenerating the architectural curriculum into a flexible structure, empowering students to structure their education based on their own goals and aspirations as architects. This new educational structure enables the development of practical skills and competencies required in practice, but also the far-reaching goal of preparing future architects for global, cultural, environmental complexities. Ultimately, we believe that a flexible expanded roster of curricular options enhances the architect’s ability to analyse, synthesise, and communicate. In this new paradigm, we envision design teams as interdisciplinary, where architect/general practitioners work with architect/simulationists, architect/construction managers, structural engineers, and other construction professionals, in close collaboration.

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