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November 2016 vol. 3 num. 1

XX Congreso de la Sociedad Iberoamericana de Gráfica Digital

Published articles (151)

About the event

Committee

Statistics

Presentation

Carta del Presidente- [Open Access](#)

XX SIGRaDi

[Herrera, Pablo C.](#);[PDF](#) - p.i-ii

1. Teorías y Prácticas de Diseño en Contextos Digitales - DDIS

Full Article- [Open Access](#)

Enhancing Flexibility of 2D Planar Materials By Applying Cut Patterns For Hands On Study Models

[Güzelci, Orkan Zevnel](#); [Alacam, Sema](#); [Bacinoğlu, Zevnep](#);[PDF](#) - p.1-6Full Article- [Open Access](#)

Mapeo digital a través de la diversificación de pequeños recursos visuales para potenciar la creatividad y la autonomía de los estudiantes de primer año en el taller de proyecto

[Fernández, Hernán Ascui](#); [Jiménez, Nelson Arias](#);[PDF](#) - p.7-13Full Article- [Open Access](#)

Digital mediation and occupation of public space: hybrid spaces for connection and cultural resistance

[Trujillo, Juliana Couto](#); [Alves, Gilfranco Medeiros](#);[PDF](#) - p.14-19Full Article- [Open Access](#)

Traçado: recursos computacionais aplicados no processo de projeto de mobiliário urbano permanente

[Digiandomenico, Dyego](#); [Landim, Gabriele](#); [Fischer, Henrique](#);[PDF](#) - p.20-25Full Article- [Open Access](#)

Mil edificios, procesos maquínicos en estrategias proyectuales complejas

[Miret, Santiago](#);[PDF](#) - p.26-33Full Article- [Open Access](#)

Entendendo o Design Digital: o designer nos processos digitais de projeto

[Makert, Rodrigo](#); [Alves, Gilfranco](#);[PDF](#) - p.34-41Full Article- [Open Access](#)

Computação material: um estudo sobre a atualização geométrica de elementos vazados na arquitetura

[SANTANA NETO, Ernesto José de](#); [SILVA, Robson Canuto da](#);[PDF](#) - p.42-49Full Article- [Open Access](#)

Imagens Digitais na Apresentação de Projetos de Arquitetura: estudo na arquitetura brasileira contemporânea – Jacobsen Arquitetura

[Stumpp, Monika Maria](#); [Braga, Gisele Pinna](#);[PDF](#) - p.50-57Full Article- [Open Access](#)

Arquitectura Sónica de Pulsación digital: Diseño interdisciplinar paramétrico y fabricación digital aplicada a instrumentos musicales e instalaciones sonoras

[Goldemberg, Eric](#);[PDF](#) - p.58-64Full Article- [Open Access](#)

Gestão de projeto interdisciplinar: smart design, design de interação, materialização e projeto de alta complexidade

[Pazmino, Ana Verônica](#) ; [Braga, Rodrigo](#); [Pupo, Regiane](#);[PDF](#) - p.65-70Full Article- [Open Access](#)

Taxonomias de Geometria da Arquitetura Contemporânea como elementos didáticos para a prática do Projeto Paramétrico

[Pires, Janice de Freitas](#); [Gonçalves, Alexandre](#); [Pereira, Alice Therezinha Cybis](#);[PDF](#) - p.71-77Full Article- [Open Access](#)

Um modelo de fluxo para design de livro digital infantil

Teixeira, Deqlaucy Jorge; Maritan, Bruna Bertolazi; Goncalves, Berenice S.;	PDF - p.78-85
Full Article- Open Access	
Square Design: from digital analysis to urban design	
Pezzica, Camilla; Lopes, João V.; Paio, Alexandra;	PDF - p.86-93
Full Article- Open Access	
Entre representações, parâmetros e algoritmos: um panorama do ensino de projeto de arquitetura em ambiente digital na América Latina	
Vasconcelos, Tássia Borges de.; Sperling, David Moreno;	PDF - p.94-100
Full Article- Open Access	
O conceito de Performance e sua apropriação no campo do Design Computacional	
Nisenbaum, Marcio;	PDF - p.101-106
Full Article- Open Access	
Representação de Patrimônio a partir do Desenho Paramétrico como Processo Formativo para o Projeto	
Silva, Adriane Borda Almeida da; Brum, Valentina Toaldo;	PDF - p.107-112
Full Article- Open Access	
Towards a new Datascape	
Santiago, Albarracín;	PDF - p.113-117
Full Article- Open Access	
Naturaleza, Sinergia, Tensegridad y Biotensegridad, ¿es 1 + 1 = 4?	
Castro Arenas, Cristhian; Miralles, Monica ;	PDF - p.118-122
Full Article- Open Access	
IMPACTO DEL MUNDO DIGITAL SOBRE LAS REPRESENTACIONES GRÁFICAS DEL DISEÑO ARQUITECTÓNICO LA EXPERIENCIA EN EL TALLER VIRTUAL DE ARQUITECTURA IV–UPC–UNNE	
Bianchi, Alejandra S.; Tripaldi, Gustavo A.; Pintos, Gladis E.; Iturriaga, José B.; Vargas, Sergio D.;	PDF - p.123-128
Full Article- Open Access	
Interfaces em Ação: sobre interações e layers comunicacionais nas práticas de projeto remoto	
Santos, Denise Múnaco dos; Martinez, Andressa Carmo Pena; Souza, Douglas Lopes de; Brinati, Paola de Moraes;	PDF - p.129-135
Full Article- Open Access	
Un espacio personal en la web	
Tosello, María Elena; Colombo, María Georgina Bredanini;	PDF - p.136-141
Full Article- Open Access	
El espacio-interfaz: un lugar habitable	
Tosello, María Elena ;	PDF - p.142-148
Full Article- Open Access	
Objectile e o projeto paramétrico	
Duarte, Rovenir Bertola; Lepri, Louisa Savignon; Sanches, Malu Magalhães;	PDF - p.149-156
Full Article- Open Access	
Smartness and Interactiveness in Architecture	
Lonsing, Werner;	PDF - p.157-164
Full Article- Open Access	
Reconfiguración del aula escolar – un análisis sensorio de la interacción alumno-maestro	
Cardellino, Paula; Araneda, Claudio;	PDF - p.165-169

2.Enseñanza en Contextos Digitales e Historia de los Medios - MHIS

Full Article- Open Access	
Controlled Transformations: A method to introduce first year architecture students to digital and parametric design thinking	
Vamvakidis, Gerasimos Simos;	PDF - p.170-174
Full Article- Open Access	
La importancia del Trabajo Colaborativo en la enseñanza de la Metodología de Diseño de Proyectos	
Peña, María Magdalena;	PDF - p.175-179
Full Article- Open Access	
FOTOGAMETRIA ESFÉRICA: UMA TÉCNICA DE BAIXO CUSTO PARA DOCUMENTAÇÃO ARQUITETÔNICA	
Bastian, Andrea Verri;	PDF - p.180-187
Full Article- Open Access	
PROJETO SIMULTÂNEO: A formação do profissional contemporâneo e o mercado da construção civil	
Menezes, Alexandre Monteiro de; Viana, Maria de Lourdes Silva; Pereira Junior, Mario Lucio; Palhares, Sérgio Ricardo;	PDF - p.188-193
Full Article- Open Access	
DISEÑO ESPECULATIVO, CO-CREACION Y CASA DEL PUENTE. Un caso de prácticas didácticas en entorno post-digital en la carrera de Arquitectura	
Barros, Diana Rodríguez; Mandagarán, María.;	PDF - p.194-200

Full Article- Open Access	CULTURA HACEDOR, MODELIZADOR PARAMETRICO Y PROTOTIPADO DIGITAL. Un caso de prácticas didácticas en entorno post-digital en la carrera de Diseño Industrial	PDF - p.201-205
Barros, Diana Rodriguez; Pellizzoni, Pablo;		
Full Article- Open Access	Enseñanza en la Era Digital: La Empatía Docente y el Aprendizaje Colaborativo	PDF - p.206-210
Espinoza, Verónica Paola Rossario;		
Full Article- Open Access	Investigación Didáctica colectiva: Caso Taller de Proyecto Arquitectónico 1- Matemática	PDF - p.211-218
Bessone, Miriam; Imbach, Graciela; Costa, Matías Dalla; Fritz, Soledad;		
Full Article- Open Access	Entre el pensar y el hacer avanzados	PDF - p.219-226
Frogheri, Daniela; Estévez, Alberto T.;		
Full Article- Open Access	Estrategias para la promoción social en el Distrito de Innovación de Medellín, Colombia. Primer Taller de Diseño Experimental para la Ciudad.	PDF - p.227-230
Molinas, Isabel Sabina; Cuartas, Coppelia Herrán; Mazo, Ever Patiño; Castaño, Julián Antonio Ossa;		
Full Article- Open Access	A Inserção do Desenho Paramétrico em Estágios Iniciais do Curso de Arquitetura e Urbanismo a partir do Estudo de Superfícies Curvas	PDF - p.238-243
Vecchia, Luísa Félix Dalla; Brum, Valentina Toaldo; Silva, Gabriel Martins da; Silva, Adriane Borda Almeida da;		
Full Article- Open Access	Projetando com Blocos de Montar Digitais: Possibilidades e Limitações do Jogo LEGO Digital Designer	PDF - p.244-251
Braidá, Frederico; Castro, Janaina Mendes de; Pires, Letícia Bedendo Campanha; Pereira, Luiz Antônio Rozendo; Cardoso, Marcela Martins Cavalari;		
Full Article- Open Access	EBA aumentada: happening-inauguração em espaço híbrido	PDF - p.252-259
Paraizo, Rodrigo Cury; Fabião, Aline Couri; Medeiros, Marina Lima;		
Full Article- Open Access	A Public Space for the Digital Age	PDF - p.260-265
Riether, Gernot;		
Full Article- Open Access	Relacionamiento Entre los Talleres de Arquitectura y el Laboratorio de Fabricación Digital	PDF - p.266-271
Bonifácio, Paulo Adhemar Pereyra; Terradas, Ximena Echavarría; Flores, Luis; Meirelles, Lucía;		
Full Article- Open Access	Cidade digital: a construção de shapefiles públicos como ambiente de ensino, pesquisa e extensão	PDF - p.272-277
Santos, Ademir Pereira dos; Leite, Denivaldo Pereira; Pereira, Ivan Augusto Alves; Okinaga, Cesar Hiro;		
Full Article- Open Access	[PARA] métricas do patrimônio arquitetônico pelotense	PDF - p.278-284
Vasconcelos, Tássia Borges de; Silva, Adriane Borda Almeida da; Vecchia, Luísa Félix Dalla;		
Full Article- Open Access	Creación asistida por tecnología	PDF - p.285-289
Granero, Adriana Edith; Paqanini, Ana Livia; Paqanini, Ana Livia; Paqanini, Ana Livia; Hölzel, Gabriel;		

3.Fabricación y Construcción Digital - DFAB

Full Article- Open Access	A Fabricação Digital e o Papel da Arquitetura para uma Mudança de Paradigma Tecno-Econômico no Setor da Construção Civil	PDF - p.290-296
Borges, Marina Ferreira;		
Full Article- Open Access	Protótipo de dispositivo facilitador para digitalização 3D por fotogrametria com smartphones	PDF - p.297-304
Dantas, Paulo Victor de Farias; Ribeiro, Thiago Rafael Rodrigues; Bruscato, Underléa Miotto; Silva, Fabio Pinto da;		
Full Article- Open Access	O futuro do processo construtivo? A impressão 3d em concreto e seu impacto na concepção e produção da arquitetura	PDF - p.305-309
Florêncio, Eduardo Quintella; Ferreira Segundo, Dilson Batista; Quintella, Ivvy Pedrosa Cavalcante Pessôa;		
Full Article- Open Access	Making pavilions: Os pavilhões temporários no contexto das faculdades de arquitetura e urbanismo	PDF - p.318-325
Quintella, Ivvy Pedrosa Cavalcante Pessôa; Florêncio, Eduardo Quintella; Ferreira, Ítalo Cintra;		
Full Article- Open Access	Tecnologia no Desenvolvimento da Arte Interativa	PDF - p.326-330
Santos, Gabriela Bonifacio dos; Raposo, Marinah; Matta, Roberto Da; Cavalcanti, Caio;		

Full Article- Open Access Análisis comparativo de prendas y estructuras textiles realizadas por impresión 3D Tapiá, Clara ;	PDF - p.331-336
Full Article- Open Access O uso do conceito paramétrico aplicado a uma inovação no mobiliário urbano: estudo de caso bicicletário Silva, Luciano Santos da ; Barbieri, Gabriel ; Bruscato, Underléa Miotto ; Silva, Fabio Pinto da ;	PDF - p.337-341
Full Article- Open Access A transição do modo de viver e projetar cidades: Mobilidade Sustentável e as novas tecnologias Silva, Jady Medeiros ; Maziviero, Maria Carolina ;	PDF - p.342-346
Full Article- Open Access La transferencia y las asociaciones colaborativas Muñoz, Patricia ;	PDF - p.347-351
Full Article- Open Access Geometría avanzada para espacios de gestión ciudadana: un enfoque desde la Creatividad Colectiva Martin-Mariscal, Amanda ; Martin-Pastor, Andrés ; López-Martinez, Alicia ; Chiarella, Mauro ;	PDF - p.352-359
Full Article- Open Access Tipografía tátil Cruz, Luciana Eller ; Maynardes, Ana Claudia ;	PDF - p.360-365
Full Article- Open Access Choosing the Partner in a Digital Fabrication Case Miyasaka, Elza Lulj ; Paoletti, Ingrid ; Fabricio, Marcio Mintz ;	PDF - p.374-380
Full Article- Open Access Fabricação digital e identidade de territórios em produtos cotidianos Júdice, Andrea Castello Branco ; Maynardes, Ana Cláudia ; Júdice, Marcelo Ortega ; Aviani, Francisco Leite ;	PDF - p.381-386
Full Article- Open Access Arquitetura inclusiva: a planta tátil como instrumento de projeto colaborativo com portadores de deficiência visual MUSSI, Andréa Quadrado ; ROMANINI, Anicoli ; LANTELMF, Elvira ; MARTINS, Marcele Salles ;	PDF - p.387-393
Full Article- Open Access vMESH : How to print Architecture? Raspall, Felix ; Bañón, Carlos ;	PDF - p.394-398
Full Article- Open Access Ciudad Vieja; un modelo para armar. Bonifácio, Paulo Adhemar Pereyra ;	PDF - p.399-404
Full Article- Open Access Simplified for Resilience: A parametric investigation into a bespoke joint system for bamboo Matson, Carrie Wendt ; Sweet, Kevin ;	PDF - p.405-411
Full Article- Open Access Parametrically Fabricated Joints: Creating a Digital Workflow Cormack, J. ; Sweet, K.S. ;	PDF - p.412-417
Full Article- Open Access Form-finding to fabrication of super-thin anisotropic gridshell Naboni, Roberto ;	PDF - p.418-425
Full Article- Open Access Artesanía en Latinoamérica: Experiencias en el contexto de la Fabricación Digital Herrera, Pablo C. ;	PDF - p.426-432
Full Article- Open Access Praiseworthy Competition → ^ ← Past: Design-through-Production: from Analysis to Formulation Klinger, Kevin B. ;	PDF - p.433-440
Full Article- Open Access Design de Contraixo Elétrico e Aplicação da Prototipagem 3D Alló, Letícia ; Pazmino, Ana Veronica ;	PDF - p.986-990

4. Información, Modelos y Simulaciones - BIM

Full Article- Open Access Dieste Ex Machina. Tecnología y patrimonio Álvarez, Marcelo Pavssé ; Amen, Fernando Garcia ;	PDF - p.441-445
Full Article- Open Access Evaluación de las condiciones de orientación temporal en programas de modelación luminica	

Leonard, Francisca Rodríguez ;	PDF - p.446-452
Full Article- Open Access	
As estratégias dos projetos digitais de Tom Wiscombe	
Lima, Fábio; Furtado, Neander;	PDF - p.453-458
Full Article- Open Access	
Explicitando a estrutura do prédio em modelos BIM	
Menegatto, José Luis;	PDF - p.459-465
Full Article- Open Access	
Análise da integração da modelagem gerativa com BIM: interoperabilidade, potenciais e fluxo do processo no par Revit® - Dynamo	
Souza, Douglas Lopes de; Costa, André Teixeira da; Martinez, Andressa do Carmo Pena; Santos, Denise Mónico dos ;	PDF - p.466-470
Full Article- Open Access	
Geoinclusão: Sistemas de Informação Geográfica e Crowdthinking	
Muniz, Leonardo Oliveira; Marino, Tiago Badre; Silva, Jorge Xavier da;	PDF - p.471-475
Full Article- Open Access	
Crowdthinking-Crownlearning com BIM	
Granero, Adriana Edith; Calquín, Danny Lobos;	PDF - p.476-480
Full Article- Open Access	
Cidades Inteligentes e City Information Modeling	
Amorim, Arivaldo Leão de;	PDF - p.481-488
Full Article- Open Access	
Análise comparativa do processo de extração do padrão COBie entre ferramentas BIM de projeto	
Brandão, Fernanda Prado; Machado, Fernanda Almeida; Teles, Roberta Pinto;	PDF - p.489-496
Full Article- Open Access	
A implantação de BIM: usos, atividades e processos na fase inicial da projeção	
Pereira, Ana Paula Carvalho; Amorim, Arivaldo Leão de;	PDF - p.497-504
Full Article- Open Access	
A utilização do HBIM na documentação, na gestão e na preservação do Patrimônio Arquitetônico	
Tolentino, Mônica Martins Andrade;	PDF - p.510-518
Full Article- Open Access	
Urbanismo Paramétrico: Experimentos para uma cidade compacta e sustentável	
Silva Junior, Edgard Rosa;	PDF - p.519-527
Full Article- Open Access	
Estudo de detalhamento estrutural da Catedral de Palmas – TO, Brasil	
Lacroix, Igor; Paranhos, Paulo Henrique; Aviani, Francisco Leite; Silva, Neander Furtado;	PDF - p.528-533
Full Article- Open Access	
Adequação da Modelagem Digital de Espaços Arquitetônico para a Visualização com Tecnologia de Jogos Digitais	
MACHADO, Roger; Heidrich, Felipe Etcheagaray ;	PDF - p.534-538
Full Article- Open Access	
Referências Digitais para Visualização de Possibilidades de Organização do Espaço Arquitetônico	
Heidrich, Felipe Etcheagaray ;	PDF - p.539-543
Full Article- Open Access	
Cidade Dinâmica: Ferramentas digitais em prol do planejamento urbano	
Caldeira, Keila Fernanda Gomes; Pinheiro, Rafael Lemieszek;	PDF - p.544-549
Full Article- Open Access	
O desenvolvimento de um sistema de proteção de fachadas cinéticas: um protótipo responsivo ao comportamento do usuário	
Stofella, Arthur; Bertoli, Luiza Figueiredo; Vaz, Carlos Eduardo Verzola; Kós, José Ripper;	PDF - p.550-555
Full Article- Open Access	
Gestão de Obras com BIM – Uma nova era para o setor da Construção Civil	
Bomfim, Carlos Alberto Andrade; Lisboa, Bruno Teixeira Wildberger; Matos, Pedro Cesar Correia de;	PDF - p.556-560
Full Article- Open Access	
A representação do espaço de arquitetura por meio de dispositivos táteis: uma revisão conceitual e tecnológica	
Peronti, Gabriela Gonzalez; Silva, Adriane Almeida Borda da; Veiga, Mônica;	PDF - p.561-566
Full Article- Open Access	
Antropoplástico: Desdobramentos em arte a partir do desenho paramétrico e da fabricação digital	
Guedes, Thiago Matheus Costa; Acosta, Daniel Albernaz; Borda, Adriane; Ferreira, Cristiano Correa; Peronti, Gabriela Gonzalez; Brum, Valentina Toaldo;	PDF - p.567-571
Full Article- Open Access	
Purple Haze vs Don Giovanni: a experiência de mashup no Pavillion 21 MINI Opera Space de Coop Himmelb(l)au	
Costa, Philline Cunha da;	PDF - p.572-578

Full Article- [Open Access](#)

From Parametric to Meta Modeling in Design

[Bernal, Marcelo](#);

[PDF](#) - p.579-583

5. Información, Procesamiento y Visualización - IPVIS

Full Article- [Open Access](#)

Views on architecture: Different abstraction layers of building information imply special working methods and interaction metaphors to support a variety of courses of action

[Langenhan, Christoph](#); [Petzold, Frank](#);

[PDF](#) - p.584-589

Full Article- [Open Access](#)

Realidad Virtual como medio de representación de la experiencia especial: Su uso en el diseño participativo

[Montiel, Constanza](#); [Lovola, Mauricio](#);

[PDF](#) - p.590-594

Full Article- [Open Access](#)

La Trazabilidad del patrimonio arquitectónico del Estado

[Folga, Alejandro](#); [Sena, Leonardo Gómez](#);

[PDF](#) - p.595-600

Full Article- [Open Access](#)

Otimização multi-objetivo e Desenvolvimento Orientado pelo Transporte: algoritmos evolutivos em estratégias de planejamento urbano

[Lima, Fernando](#); [Kos, Jose Ripper](#); [Montenegro, Nuno](#);

[PDF](#) - p.601-608

Full Article- [Open Access](#)

Design de embalagem e visualização de dados: uma perspectiva do grid tipográfico

[Scanavino, Hernan Daniel](#); [Campos, Gisela Belluzzo de](#);

[PDF](#) - p.614-619

Full Article- [Open Access](#)

Design Gráfico de Comunicação Visual Urbana como Espaço Instalativo

[Santos, Angela Maria dos](#); [Campos, Gisela Belluzzo de](#);

[PDF](#) - p.620-624

Full Article- [Open Access](#)

Hacia una Instantánea Urbana. Captura, Lectura y Manejo Automático de Información en Forma de Personas a Partir de Registros Videográficos a Nivel de Observador

[Gutiérrez, Claudio Aráneda](#); [Laurie, Braulio Gaticas](#);

[PDF](#) - p.625-629

Full Article- [Open Access](#)

Parametric 3d wind loading on hemispheric dome structures

[Silva, Felipe Tavares da](#);

[PDF](#) - p.638-644

Full Article- [Open Access](#)

Datos sonificados para la improvisación visual

[Soto, Bruno Perelli](#); [Pinto, Eduardo Hamuy](#); [Traverso, Rolando Cori](#);

[PDF](#) - p.645-650

Full Article- [Open Access](#)

Pontos (de vista) sobre o patrimônio: entre o escaneamento e a fotogrametria

[Silva, Adriane Borda Almeida da](#); [Silveira, Diego Sacco](#); [Medina, Alex](#); [Vecchia, Luisa Félix Dalla](#);

[PDF](#) - p.651-656

Full Article- [Open Access](#)

Visualização de Modelos Digitais: Informação dos Edifícios em Canteiro de Obras

[Brochardt, Mikael](#); [Andrade, Max](#); [Assis, Jonas](#);

[PDF](#) - p.657-661

Full Article- [Open Access](#)

Aplicações de Realidade Aumentada no Canteiro de Obras

[Assis, Jonas H. G. de](#); [Andrade, Max L. V. de](#); [Brochardt, Mikael M. de S. A.](#);

[PDF](#) - p.662-667

Full Article- [Open Access](#)

Sentimentality and the Digital Expanse

[Bono, James De](#); [Moleta, Tane](#);

[PDF](#) - p.668-676

6. Morfogénesis, síntesis y análisis de las formas - MORF

Full Article- [Open Access](#)

Colonna Curva: A case study on curved folding for the production of architectural components

[Hemmerling, Marco](#); [Mazzucchi, Alessio](#);

[PDF](#) - p.677-680

Full Article- [Open Access](#)

Babiy Yar: análise do edifício digital, metáfora do holocausto nazista

[Lima, Fábio](#); [Furtado, Neander](#);

[PDF](#) - p.681-685

Full Article- [Open Access](#)

A visualização espacial através da modelagem paramétrica e da fabricação digital em edifícios curvilíneos de Oscar Niemeyer no Memorial da América Latina

[Veiga, Breno Tisi Mendes da](#); [Florio, Wilson](#);

[PDF](#) - p.686-692

- Full Article- [Open Access](#)
El espacio arquitectónico topológico digital
 Granero, Adriana Edith; [PDF](#) - p.693-698
-
- Full Article- [Open Access](#)
Design gráfico-sonoro em projetos interativos em tecnologias livres
 Campos, Gisela Belluzzo de.; Espindola, Fábio; [PDF](#) - p.699-703
-
- Full Article- [Open Access](#)
Desafiando a Gravidade: da estática à dinâmica, de objetos a sistemas
 Henriques, Goncalo Castro; Passaro, Andrés; [PDF](#) - p.704-709
-
- Full Article- [Open Access](#)
Exploring Weaire-Phelan through Cellular Automata: A proposal for a structural variance-producing engine
 Araujo, André L.; Celani, Gabriela; [PDF](#) - p.710-714
-
- Full Article- [Open Access](#)
O estudo das operações formais no processo de projeto do arquiteto Peter Eisenman
 Martinez, Andressa Carmo Pena; Santos, Denise Mônaco dos; Souza, Douglas Lopes de; Castriotto, Caio Magalhães; [PDF](#) - p.715-719
-
- Full Article- [Open Access](#)
Embedding auxetic properties in designing active-bending gridshells
 Naboni, Roberto; Pezzi, Stefano Sartori.; [PDF](#) - p.720-726
-
- Full Article- [Open Access](#)
O meu modo de morar: uma gramática para reformar projetos de apartamentos
 Griz, Cristiana; Mendes, Letícia; Amorim, Luiz; Holanda, Maria Augusta; Carvalho, Thais; [PDF](#) - p.727-733
-
- Full Article- [Open Access](#)
Del microscopio electrónico a la estrategia digital en arquitectura
 Estévez, Alberto T.; Navarro, Diego; [PDF](#) - p.734-742
-
- Full Article- [Open Access](#)
Estruturas Complexas Adaptativas: Modelagem Analógica integrada à Parametrização e Comutação Física
 Real, Clara; Ribeiro, Clarissa; Nobre, Emanuelle; Nunes, Yasmin; Medeiros, Petrick; Freitas, Lara; [PDF](#) - p.743-747
-
- Full Article- [Open Access](#)
Pathways for Testing Environmental Building Performance
 Holzer, Dominik; [PDF](#) - p.748-753

7. Interfaces y Dispositivos - INTF

- Full Article- [Open Access](#)
Componente Responsivo para Fachadas: Análise e Validação
 Barnuevo, Thales; Sordi, Lucas De; Silva, Leandro; Silva, Neander Furtado; Aviani, Francisco Leite; [PDF](#) - p.754-760
-
- Full Article- [Open Access](#)
A influência dos dispositivos portáteis de leitura no design do livro digital
 Dick, Maurício Elias; Goncalves, Berenice Santos; Pereira, Alice Teresinha Cybis; Vieira, Milton Luiz Horn; [PDF](#) - p.761-768
-
- Full Article- [Open Access](#)
Meta-Lab: programação de um laboratório interativo
 Abreu, Sandro Canavezzi de; Vasconcelos, Guilherme Nunes de; Stralen, Mateus van; [PDF](#) - p.769-775
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-
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Módulos Eletrônicos Interativos: Cibernética e Indeterminação para a Exploração e Aprendizagem em Design
 Mattos, Erica Azevedo da Costa e; Silva, Diego Fagundes da; [PDF](#) - p.782-789
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Parametrização para além do processo de projeto: experimentando aberturas para interação
 Gomes, Maria Cecília Rocha Couto; Santos, Ana Paula Baltazar dos; Arruda, Guilherme Ferreira de; Cabral Filho, José dos Santos; Silva, Luís Henrique Marques de Oliveira; Diniz, Luiza Encarnação; Lima, Mariana Julia Souza Barbosa; Stralen, Mateus de Sousa van; [PDF](#) - p.790-794
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This paper presents a partnership organization of several enterprises to build a pavilion in Expo 2015. Cutting edge technology, cooperation and collaboration associated with communication systems are the key issues to success in a global market.



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Keywords: Industry 4.0, Collaboration, Cooperation, Digital Fabrication, Civil Construction,

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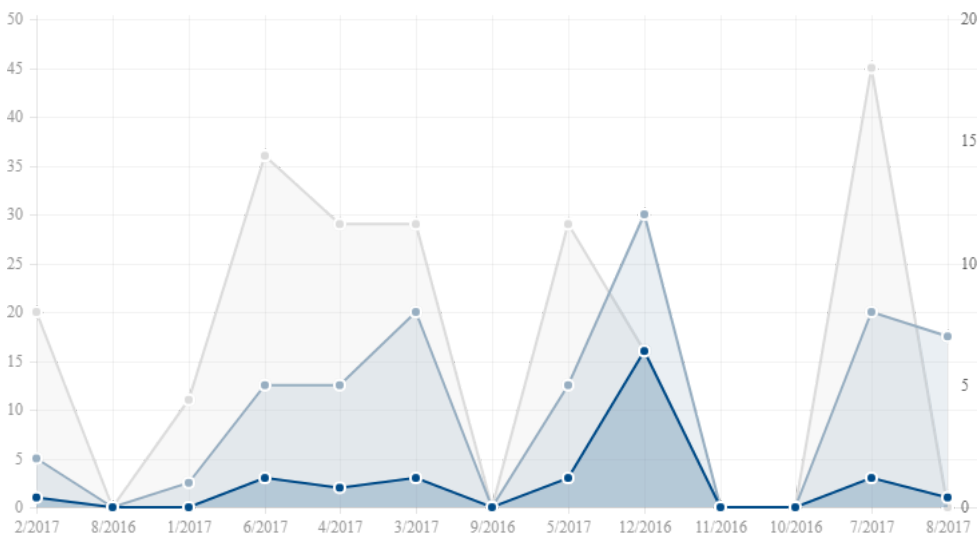
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Choosing the Partner in a Digital Fabrication Case

A Escolha dos Parceiros em um Caso Fabricação Digital

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Abstract

This paper presents a partnership organization of several enterprises to build a pavilion in Expo 2015. Cutting edge technology, cooperation and collaboration associated with communication systems are the key issues to success in a global market.

Keywords: Industry 4.0, Collaboration, Cooperation, Digital Fabrication, Civil Construction.

1. Introduction

The choice of the operators in a building process organization is as important as design, production and construction. This is due to the fact that in recent years in AEC (Architecture Engineering Construction) sector some firms have proposed complex buildings using affordable cutting edge technologies in terms of design, material, production and assembling i.e. digital fabrication. The organization that is usually used to build these projects include adding partnerships and collaboration endeavors with enterprises that have different skills and specializations. To that end, this paper discusses the various partnership choices across the world to construct the pavilion in EXPO Milan 2015.

Some authors believe we are in the 3th Industrial Revolution; signing the 1st revolution was held with hydraulic energy, the 2nd with electricity, mass production (production line) and the electronics; and the current revolution as the informatics digital revolution. Some others consider that now it is the 4th Industrial Revolution separating the electricity from electronics. However, all agree that we are in the beginning of a new revolution, thanks to the transformations associated to the digital technology in all aspects of society and economy. This actual context is characterized by various tools connected to the Internet including the possibility of advanced personalized customization, equipment and machines with high technology, and digital fabrication (Naboni & Paoletti, 2015)); also a complex system related to production and market associated with real time cloud data storage Potti (2015).

Schwab (2016) points out 3 reasons that the last industrial revolution is underway:

- a. velocity: the new technology capable to interconnect the world;
- b. breadth and depth: leading the paradigm to change our way of life, the economy, the business society and individuality.
- c. Impact on the system: transforming entire systems, across (and within) countries, companies, industries and society as a whole.

According to him, the Industry 4.0 is the possibility to produce new product processes, manufacturing systems and cooperation in a flexible way (Schwab, 2016, p. 71).

The cutting edge companies are using several strategies as: digital technology, cloud services, mobile access by apps, sensors in products and ecosystems, registered multiplication data, automated production robots, personalized e-commerce producing information trends, startup experiments, artificial intelligence and Nano connectors. The values and prices of goods are moving according to the activities associated with a smart way of producing and, services are focused on quality for customers, and efficient logistic maintenance of a competitive environment (Biase 2015).

To be part of this complex process building construction is essential to be associated with an integrated net of collaborators with skills on several disciplines to add each other with the same objective that in the end is to build the pavilion.

1.1. The Industrial Context of Digital Fabrication

The term Industry 4.0 was first used in Germany in 2011 to announce a government project to develop a high-tech digitalization of the manufacturing industry. Industry 4.0 is a digital industrial system, ecosystem of factories, machines and intelligent objects, capable of communicating and interacting with each other and with the customers. Innovation is the center issue and is based on robotics, nanotechnology and additive manufacturing. The digital transformation is seen in automation, availability of large data

files, direct access to the client by internet and connectivity obtained through the internet. The most important is the paradigm shift: in the global era production is not centralized, but where the goods are consumed; it disseminates knowledge not the product; production is bottom up aggregating production functions to the artifact. Therefore, the production is based on a tripod (1) it is possible have personalized products, like clothing, food and medicine; (2) new machines analyze massive data sets comparing individual data and produce personal objects, and (3) in this personalized production, the customer is an actor and responsible for such decisions (Larizza, 2015).

The globalization theme can be discussed from many points of view, from ancient times, when the eastern commerce enriched with oriental goods, or in the 20th century, with the dissemination of cultures and customs or in the present days with communication system creating a World Wide Web in real-time connectivity. The definition of globalization as “...a condition characterized by the presence a single sociopolitical space on a planetary scale” was introduced by Batelson (2010), and it fits this real concept very well. As expected, the civil construction is also influenced by the changes in everyday situations and; the participation of many actors and enterprises from different places in the construction of buildings is an example of the reality of this globalization.

Drewer (2001) describes that since the late 1960s global construction activities have become more concentrated within the richer industrialized countries. Furthermore, during this period an international construction system has emerged that is dominated by practices, contractors and material producers as well as by technologies and procedures that originated in these same countries. Consequently, the richer countries dominate somewhere between 80 and 90% of all global construction activities, either directly or indirectly through their contractors, design consultants and material producers. One explanation for their dominant role is their collective economic strengths; however, it is also due to the technologies now used internationally to carry out a complex array of different building and civil engineering projects.

The construction sector is directly related with the development of industries and its economic role. Han et al. (2010) points out that the amount of construction in the world is distributed in the global market as follows: Asia 37%, Europe 31% and North America 23%. In terms of volume, the U.S. has the biggest participation, followed by Japan, China and the UK.

The AEC market has lived through contemporaneous changes and the challenges it faces are: (1) clients are analyzing the additional services offered, such as technology transfer and risks; (2) more capabilities and resources are required with private investments, expanding large projects as integrated schemes; (3) the financing programs are fundamental to increase opportunities in the construction market; (4) there are several risks involving costs, equipment and cultural differences. To address these issues and to remain competitive and maintain their competitive edge, the contractors have implemented partnerships (Han et al., 2010),

Cooperation-based alliance with various collaborators is a complex undertaking in civil construction. Cheah, Garvin, Miller (2004) discuss strategies of global construction firms, citing that success is derived from different modes of operational, financial, technological and human-related conditions. For example:

... the success of Japanese contractors is attributed to their technological superiority, financial capacity, skills of forming strategic alliance with host governments and local firms (Han et al., 2014, p. 736).

In this context of contemporary Industrial Revolution, the principal activities focus on industries and services, as Perissich (2016) explains that the main determining growth factors are: increase outsourcing with their own competency; the trend to sell service by industries, not the commodity or product and a general manufacturing growth trend. The term Business Services are characterized as net enterprises with capacities and competencies to better improve a product for clients, and net organizations are able to provide solutions, results and create new services collectively, with the collaboration of large and small enterprises.

In the context and circumstances of this era the efforts are focused on the net market tendency, where society behavior is changing and it is central to be associated with partners that have different skills to expand competitiveness. As analyzed by Comu, Taylor, Messner (2012), the reasons behind these associations are to reduce costs, for customers and projects, better service, to increase quality and shorter project cycle times. Also included are hybrid business arrangements with collaborative combinations in cutting-edge technology and competitiveness. The complexity of projects reinforces the need for different and specialized suppliers from several countries.

The collaboration process considers the participation of two or more firms or persons, working together, sharing knowledge, learning and building consensus to reach the same goal. Within the benefits are, “...improved access to information and people across the enterprise, on-demand availability of data for accelerated decision making, enterprise-wide sharing of knowledge and resources, reduced error rates...” Chiprianov (2014). Also many authors agree with “...better value, time savings, better quality, improved profit margins, and the ability to handle risks both upstream and downstream in relationships...” (Wood and Ellis, 2005; Ibem, Laryea 2014; Li et al. 2012). On the other hand, these networks also “...(1) benefit the entire industry (2) Partnering increases profits by enhancing the relationship between main contractors and subcontractors (3) Current management practices do not support cooperative networking” (Wood and Ellis, 2005).

All these contexts would not be possible without the advance of currently available technology tools, as described earlier. The evolution of Digital Tools is particularly recognized with the replacement of analogue information for digital ones, before this phase, the information was electro-mechanical, such as telegraphs, telephone, radio and TV. And further back in time the invention of the Morse code manual transmission which used a code system. Digital Tools are used for the “integration, collaboration and coordination of

work process with capabilities to support processing, communication and integration functions” (Ibem, Laryea 2014).

Information is the main managing object and concerns all participants in the civil construction supply chain. Types of workflow communication shows exchange projects to collaborate, share, or generate components. This kind of electronic information exchange is called e-Business (Schneider, 2003). Coordinating the information flow becomes easier using technology to acquire information, such as project management, even more so if the available existing software is considered.

Computational methods aimed at facilitating collaboration have focused primarily on assisting the communicative aspects of collaboration in A/E/C. These have resulted, on the one hand, in Building Information Models (BIM) that, in addition to the product's geometry, also stores many of its other attributes and can convey much more information than traditional drawings and models can. On the other hand, they have resulted in computational systems that can facilitate the management of the design and construction processes by tracking drawings, managing their different versions, and coordinating concurrent access to the information (Kalay, 2006, p. 360).

BIM software system is the platform used to manage production and supplies on real-time schedule, an information system which aggregates different disciplines at the same object and works as a competent complex visual modeling.

Another aspect is the procurement associated with technologies. Procurement in construction is a process composed of steps and activities¹ usually associated with a building construction focused on managing supplies, cost and agreed terms to a contractor client along the progress of construction (Ibem, Laryea 2014). Technologies associated to procurement are used for capturing, processing, storage and communication technologies.

The association of many work contractors, each one with different skills and individually specialized compose the team of constructors. Rahman et al. (2014) identify six perspectives of contractors regarding the importance of collaboration in the construction supply chain:

1 • CLIENT'S DECISION ABOUT THE ACQUISITION STRATEGY FOR A FACILITY E.G. BUILDING • DETERMINATION OF THE MOST APPROPRIATE WAY TO ORGANIZE THE PROCUREMENT PROCESS • ORGANIZATION OF THE PROJECT TEAM • CONSTRUCTION PRODUCTION PROCESS • APPOINTMENT OF A PROJECT MANAGER • DESIGN DEVELOPMENT PROCESS • SELECTION OF MULTI-DISCIPLINARY PROJECT TEAM • DEVELOPING THE DESIGN • CONSTRUCTION PRODUCTION PROCESS • DESIGN • PREPARATION OF CONSTRUCTION DOCUMENTS • CONSTRUCTION CONTRACT ADMINISTRATION • ESTABLISHMENT OF CLIENT'S OBJECTIVES • SELECTION AND APPOINTMENT OF DESIGNER • PREPARATION OF OUTLINE DESIGN AND COST ESTIMATES • SELECTION OF CONSTRUCTOR • START CONSTRUCTION • NEED IDENTIFICATION • SPECIFICATION OF REQUIREMENT • TENDER PROCESS AND AWARD OF CONTRACT • MANAGEMENT OF CONTRACT • TERMINATION OF CONTRACT • ESTABLISHMENT OF WHAT IS TO BE PROCURED • DECIDING ON PROCUREMENT STRATEGIES • SOLICITING FOR TENDER OFFERS • EVALUATING TENDER OFFERS • AWARDED OF CONTRACTS; AND • ADMINISTRATING CONTRACTS TO ENSURE THAT THEY COMPLY WITH REQUIREMENTS • SETTING UP OF THE PROJECT • DEFINING THE PROJECT • ASSEMBLAGE OF TEAM • DESIGN OF PROJECT • TENDERING • CONSTRUCTION; • POST PROJECT EVALUATION AND POST OCCUPANCY EVALUATION (IBEM, LARYEA, 2014, P. 19)

(i) collaboration encourages teamwork; (ii) similar racial collaboration develops cooperation between team members; (iii) stimulate information sharing; (iv) improves quality and timely project completion; (v) enhance service quality; and (vi) better communication among project members (Rahman et al, 2014, p. 418).

And Finally, the success of a partnership requires “*commitment, evaluation, equity, common goals, communication, trust, and cooperation*” (Eom Shin-Jo, 2014, p. 1953) from all the collaborators, working to find better solutions for the problems that appear in the process to build the construction.

2. Methodology Procedure for the Case Study

The data collected are based on original documents such as plants, sections, elevations, sketches and pictures, also analyzed are the communication documents, for example several reports, managing documents, organograms, chronograms, procurement documents, and others. Furthermore, the authors carried out semi-structured interviews with key actors of team work who participated in the construction project; they are design managers, project managers, site managers and etc.

The visits to the site were periodically, also visits to the participating GRC panels and factories of structures were done. These visits included talking with the design manager, design team, analyzing manufacturing plan, production and logistic to gather the questions that involve the construction project.

With the data collection, the documents are input in a database, categorized, tabulated and charted to be analyzed. All information are crossed-referenced and triangulated to construct a consistent theoretical base. Although all data are to discuss one single case in this paper, it constitutes the information that will be aggregated to other cases within the same point of view in order to carry out the content analysis and generalization in future papers.

To process the analysis included describing the workflow and discussing the participation of each firm. Cooperation and collaboration is revised according to the qualification and expertise of the participants. The paper analyzes the data with the specific aim to understand how to choose a partner in a digital manufacturing case.

3. The Project

The pavilion was for Expo Milan 2015, opened from May to October 2015, with the goal of disseminating the culture and customs of the United Arab Emirates (UAE), the exhibition theme;

Feeding the Planet, Energy for Life, in terms of content and approach, thereby maximizing their participation in the Exposition as an opportunity to showcase their own particular points of excellence² (Expo 2015 S.p.A. – Milano, 2012).

2 [HTTP://WWW.CZEXPO.COM/FILES/EXPO-MILANO-THEME-GUIDE.PDF](http://www.czexpo.com/files/expo-milano-theme-guide.pdf). ACCESSED: MAY 29, 2016.

The project design is by Foster and Partners and is one of the largest pavilions in the Expo, 5,000 m² and 3 floor levels divided in four parts: (1) the entrance is a Canyon that guide the visitor to the auditorium; (2) Block B is the theater which featured the main show, (3) Block A held the offices, staff rooms and post show: a second theater with innovative 3D projection technology; and (4) Block C which held the facilities and restaurants.

The structure of the pavilion is a steel frame covered with Glassfiber Reinforced Concrete (GRC) panels, a common material in civil construction used in a different way. The texture of all panels had ripples that are inspired on the desert's sand pattern, and the shape of the canyon panels are curved, giving a similar effect as standing in the middle of this canyon-like scenario.



Figure 1: Panels pattern texture inspired on desert sand waves. Photo: author. Date: 2016.

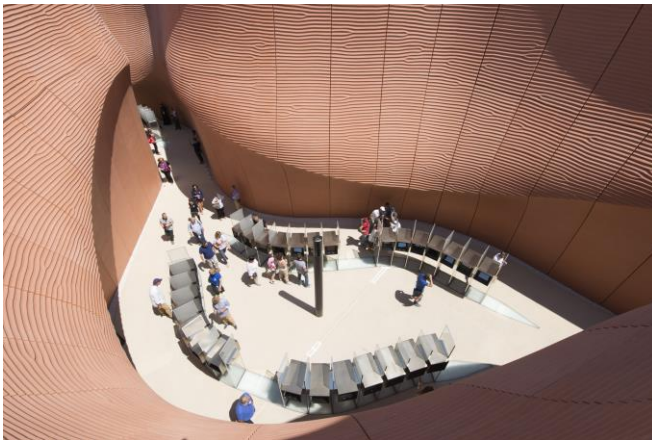


Figure 2: Canyon. Photo Nigel Young + Foster & Partners.

This is a complex building with many details and solutions, from the architecture design, interactive exhibitions, structure, substructure, different kind of curved and flat panels, junctions, technological 3D projections, extensive program, facilities, etc.

The construction project required 263 days from the design concept to the end of construction, with necessary intensive

work from many collaborators, tenders, managers in different levels, developing details, logistics, analyzing the best way to assemble, approving certificates, making mockups, testing materials and its behaviors. This work results in 129,426 man hours, that means in this complex construction of 5,000 m², the average of man work per day is 492 man hour of high quality specialization to produce this building.

Another data is the quantity of drawings needed to have all issues developed. It was 1148 shop drawings produced to this project. As the principal document for communication with all collaborators is important to mention that, as it will be discussed below, BIM information system, internet and the cloud system is fundamental to manage and exchange data with all participators, witch would not be possible with companies in different places in the world.

The 930 GRC panels are produced in Hong Kong, a resistant but fragile material that need special care to be transported. There was 18 shipments from Hong Kong to Italy with complex planned logistic, due the panels needed to be assembled according to their departure. These small data shows the complexity of the construction process and how several companies need to be organized and work as an orchestra.

4. Work Process

4.1. Team

This step analyzes the enterprises that are in the development and construction process. In the prequalification, the companies had to respond an extensive application form divided in: (1) basic information: name, address, phone, professional in charge; (2) Status: nature of the company, date when activities began, if it is a lead company; (3) financial information: turnover, forecasted turnover, audited accounts, group structure, certificate numbers; (4) Company Project Structure & Resources: number of employees, staff details, quantities, qualifications, managers, organogram. (5) Background on similar works and, (6) Client references.

The team was integrated by six main groups, as shown below,

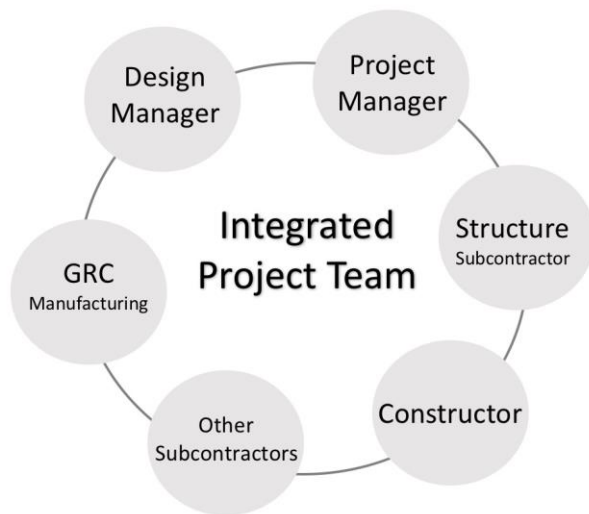


Figure 2: Integrate team for UAE Pavilion. Font: Project Manager diagram. Date: June, 2016.

Design Manager: A United Kingdom firm, Fraser and Randal, is directly connected with the client and architectural design team. This enterprise has extensive experience managing complex projects; contents such as graphics, media, interaction and environment; design, clarifying, and structuring, organizing, briefing and feedback; procurement, searching better suppliers; managing construction; cost and construction design. Here, they are responsible for Manager, monitoring the entire process, qualifying the partners, supervising costs and evaluation process and quality survey, organizing meetings, communications, qualifications of suppliers, revision and approval of all drawings, deadlines and services.

Project Manager - was composed of 2 firms: The first one, A&A Company is based in South Korea since 2000, offering solutions and executions of marketing methods, especially in the information and communication area. Its expertise is in elaboration and development of brands; applications; production, execution and input of market goods (Project Manager). In pavilion project they are also responsible for the project manager and construction consultant, answering to the specifics projects and logistics. Also, studying construction methods and inspection, and preparing timely reports and process reports.

The second one, Rimond is an Italian firm working with consulting, project managing and site manager. Their expertise is in engineering, procurement and developing infra-structure. In the UAE pavilion they conducted the compliance projects, such as sustainable issues, local licenses, verification and studying construction methods, security, hydraulics, lighting, ventilation system, and accessibility. They are also responsible for procurement, technical manager, planning and supervision of the construction site. Furthermore, they had the university as partnership in this project, doing clash detection on BIM information system and using the labs tests and simulations.

Constructor: Tecton is an Italian firm, works with the Construction of several buildings; such as churches, schools, public and financed; residential, commercial, interiors, restoration, archeology, historical buildings and monuments. In this building they are responsible for the main constructors, such as foundations, slabs, facilities, environmental and logistics manager, security and health quality and also the coordination of documentation control. At the site, they are also in charge of the project supervisor, project manager, procurement issues, architecture, engineering, the productions of subcontractors and to solve urban-related problems. Moreover, working at the site are the structure firm in charge of assembling the steel frame of the main structure and the GRC firm that assembled the construction panels.

- **Steel Frame Factory:** Stahbau Picler is an Italian factory, in the market since 1970, their expertise is in design, manufacturing and building steel frame structures and curtain wall systems. In this project the main structure was a steel frame; a complex structure associated with the substructure of the GRC panels.
- **GRC Factory:** Canbuild is from Hong Kong since 1992, specialized in managing and civil engineering, they have extensive experience in manufacturing pre-cast components. In this project they built all GRC panels with different textures. Also, the several curved panels, corner panels and small panels, the substructure was produced and aggregated on the panels by this company.

The option of choosing the firms is an example of Business Service, linked with capacities, competencies, qualification of work in specific discipline, experience, other works at similar buildings, technology used, but also on confidence and relationship. Some points are facilitated with the location of the companies, as local solutions with certification approval, laws, cultural logic and language. This net organization with several partnerships from different expertise and places improve better solutions on solve problems, using high tech equipment and machines to provide the complex system production of this building, as facilities, structure, engineering issues, panels, interior, etc.

4.2. WorkFlow

This pavilion was contracted by the United Arab Emirates MC (National Media Council) that selected a specific team to follow the project. The firm responsible for the architecture design executed the central architectural concept. The simplified diagram below shows how each workflow is organized. There are 3 main groups: 1st Group. Main Managers including the client, architecture firm and main managers; 2nd Group. Design Manager, including the architecture and coordinating engineers and; 3rd Group. Site Managers and Manufacturing Manager.



Figure 3: General Scheme of work process

The Main Manager Team includes the contractor that selected a Project group to follow the main design team, the English Architectural Design and the United Kingdom Main Manager Team, two offices under these managed all functions, such as engineering, architectural details of BIM modeling, and matters related to the construction site.

Moreover, 4 countries were represented in this organogram, the client from UAE, the United Kingdom in charge of the project and the main manager; Italy had the commitment project manager and technical drawings coordination and; Korea was in charge of project manager and manufacturing components.

The simplified organogram below shows the workflow organization to build the pavilion. As discussed before, it shows the responsibilities of the tree main groups.

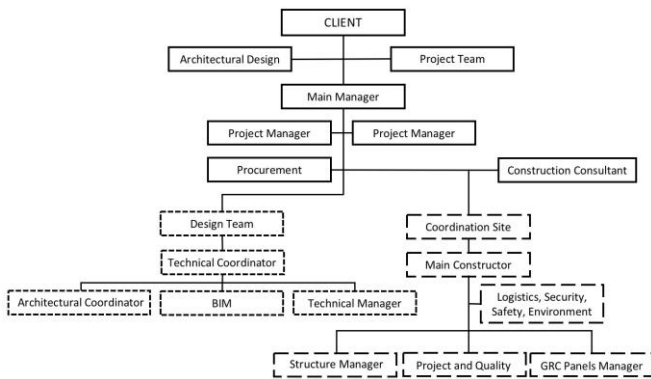


Figure 4: Organogram team workers. Font: author, date: 2016.

The Main Manager Group was committed to producing the design project, develop specific details and its approval from the design concept and then expand to the other levels, as shown below.

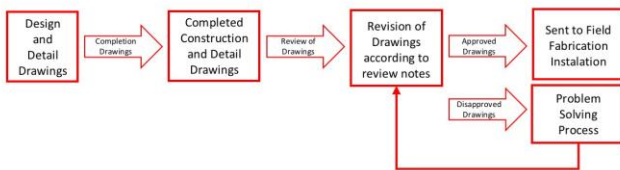


Figure 5: Design process.

From the concept to the production drawings, the approval at least three steps was necessary before it could be used in manufacturing or at the site. The Main Manager has the last word before the manufacturing and the construction, and the Project Manager has to deliver the drawings.

Design Team is committed to developing all details of the architectural design and engineering solution, using BIM

system to coordinate all drawings, which are basically three types: (1) Construction drawings included the traditional ones with plans, sections, materials and interfaces with other sectors. (2) The manufacturing drawings are produced from the design manufacturing team according to the architectural design, these are drawings for internal use and requirements profiles, cutting sizes, details, finishing, assembly of components, manufacturing elements and procurement of materials; and (3) Installation drawings are used at the site according to the requirements design, construction and manufacturing drawings, this indicates the marked parts and elements in order to allow the identification, location and connection details. All the drawings and component are identified in each code for better coordination. Periodic meetings are fundamental to synchronize the best solution for several disciplines.

BIM Model is central to coordinate exchange team information and communication in the process, increase collaboration between stakeholders; minimize conflicts, delays, reworks and material waste; reduce contracts, increase safety, performance and reduce financial liability risks; improve labor efficiency; field productivity and quality management; building components are tagged with codes and associated with related information.

The information coordination used is based on several participants with a project communication which contains the main rules to manipulate, upload and download files in an online worldwide cloud platform to be accessed by the authorized key participants. The documents included description, quantity, titles and date; recorded with an imprinted submittal date. An example shown is the choice of junction size for the panels, the architect designer wanted 2 cm for each panel; manufacturing and structure 4 cm, stating that with this dimension they could guarantee a perfect result. The deal was closed with 3 cm and required efforts from all participants. This is also a good example of cooperation within the many firms participating in order to construct the same object.

The Construction Management also worked with BIM construction scheduling, auditing quantity survey, production analysis, planned vs. actual analyses, resource balancing, technical supervision, cost control and handover control. In addition to the Constructor Management, three main firms work at the site: the main constructor, with onsite construction, concrete parts; the steel structure company assembling the beams, columns, bracing, curtain walls and stairs and the GRC panels firm, assembling and adapting it. There are other subcontractors for transport, crane, etc.

The Coordination Site is also from a Project Manager firm, which follows the design and management process. The construction methods are analyzed in depth and previously approved, as well as the logistics to use machines, office location, material storage and control. The stored materials in the base area are carried to the construction site with the help of 4D scheduling and construction simulation created with BIM model. All efforts are made for less vehicular traffic, less environmental impact, respecting the supplements needed and ensuring the maximum use of the fair-space.

Sampling and mockups are developed in different ways: (1) traditional sampling, with the materials and components used; (2) special sampling if necessary using CNC machine from the university partner; (3) Virtual sampling with the 3D Model, to make important assembly decisions, to analyze the performance or aesthetical view; (4) Mockups, specially to verify structural behavior and several envelope panels. This issue is a continuous process along design and construction.

The success of this project is seen especially with the good coordination and collaboration of the entire team, in addition to each enterprise forming a whole; this is helped with personal skills to manage the team and use affordable technological communication system available. This is thanks to the possibility of fast exchange and managing data using the BIM information system, cloud storage data and the internet. The client has been also, with the choice of such a complex organogram, deeply involved in order to set up goal and shorten construction time schedule, avoiding possible delays.

5. Discussion

Nowadays the opportunities are focused on different services offered with quality which requires partnerships with enterprises to be competent and reference to the special issues in order to be part of the competitive market, namely: product quality, price, visualizing, personalized capacity and personal relationships and material, design, production and time schedule.

Some criteria, as per the case study, could be not only hard skill i.e. Capacity of data management, BIM advanced personalized tools, international expertise, but also soft skills i.e. collaborative attitude in practice, ability to set objective and goals in relation to scope of works, problem solving attitude due to the unpredictability of complex building construction.

In Industry 4.0, the association in partnership is fundamental to reduce costs, to the customer and projects, provide better services with high quality and low cycle time. To success of building this complex pavilion it was necessary to have available digital cutting-edge equipment and machines, complex communication system and a specialized net collaborator capable to find best solutions.

The context of Business Services using Digital technologies are central tools to make possible the collaboration and coordination of the project of this case study, thanks to internet, automation manufacturing, cloud database, research access and others. Choosing the best partner means to be opened to technical skills, expertise, internal relationships and local understanding. The choice of manufacturers with know-how in their products respond to innovative automated technologies and also the partnership with the managers that in addition to their knowledge, have a good work background and a close relationship with the architects.

The paper shows out preliminarily the necessity to study and better understanding, through case studies, the global supply chain and how companies choose partnership to enable the Industry 4.0.

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