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Sommaire

Préface

La production et l'exploitation de modèles numériques s'inscrivent dorénavant dans les pratiques journalières de l'architecte que ce soit à des fins projectuelles ou patrimoniales.

Afin d'analyser, penser et expérimenter l'usage du numérique dans ces pratiques architecturales, une communauté de chercheurs s'est constituée autour d'une thématique générale identifiée sous l'appellation « architecture numérique ». Les études réalisées au sein de cette communauté couvrent de nombreux aspects de l'activité de l'architecte dans le but de le positionner comme un « utilisacteur » œuvrant pour une écologie numérique.

L'usage du numérique y est étudié au travers de ses outils logiciels et supports physiques dans l'ensemble des pratiques courantes et émergentes de l'architecte. Ces pratiques s'organisent autour du projet d'architecture, de la conception à la fabrication, mais également autour de la gestion du patrimoine bâti, de sa numérisation à sa valorisation. Elles s'insèrent dans un système hybride et interactif qu'il est nécessaire d'appréhender d'une manière holistique et interdisciplinaire afin de proposer des modèles et outils numériques efficients.

Les membres du laboratoire MAP-CRAI de l'ENSA de Nancy, et plus globalement de l'UMR MAP[1], s'inscrivent dans cette démarche scientifique en produisant et en alimentant régulièrement les connaissances sur le domaine par la publication de leurs travaux et leur participation à des conférences nationales et internationales sur l'architecture numérique ou des thèmes périphériques questionnés dans les approches proposées.

Ces cahiers de recherche proposent une sélection représentative de l'ensemble de ces travaux publiés entre 2008 et 2012. Ils ont été réalisés par les membres permanents du MAP-CRAI dans le cadre de projets régionaux ou nationaux, ou de thèses financées par la France (MENR, MCC, Région Lorraine) ou par un pays étranger (Luxembourg, Tunisie, Algérie). Les approches présentées interrogent plusieurs disciplines en réunissant des spécialistes de chacun des domaines investis : architectes, ingénieurs, informaticien, psycho-cogniticien, historien, archéologue, ...

Six grands thèmes structurent ces cahiers. Tout d'abord le thème « Environnement » présente trois approches d'assistance à la conception étudiée sous l'angle du développement durable. L'objectif est de proposer des méthodes et outils qui permettent de prendre en compte, dès les étapes initiales du projet, à la fois les différents aspects environnementaux (la lumière, la thermique, etc.) mais aussi d'évaluer plus globalement les performances environnementales des projets afin de guider le concepteur et ses partenaires dans ses décisions.

Le second thème « Matériau et construction » illustrent les travaux qui questionnent le rapport de l'architecture à la construction. Elle se fonde sur l'idée qu'une meilleure maîtrise des données techniques grâce aux outils numériques est de nature à améliorer la qualité des projets conçus en positionnant l'architecte comme acteur pivot. Sont abordés ici des questions comme celles des nouveaux modèles constructifs émergeant en particulier dans le champ des architectures « non standard » ou les approches sur la visualisation 4D dédiée à la planification de chantier.

[1] Le laboratoire MAP-CRAI est une des quatre équipes de l'UMR multi-sites MAP[2] (Modèles et simulations pour l'Architecture et le Patrimoine). UMR MAP n°694 CNRS/Ministère de la Culture et de la Communication. www.map.archi.fr

Le thème « Morphologies numériques » s'intéresse la question de la conception de la forme en architecture. Cette dernière connaît aujourd'hui des bouleversements importants avec l'émergence d'outils à fortes capacités génératives. On présente ici plusieurs approches qui situe l'émergence de cette forme dans un « continuum numérique » allant de l'idée à la réalisation. Deux travaux abordent la genèse de la forme dans sa relation au processus constructif et le troisième fait apparaître l'intérêt de l'algorithmique génétique dans la recherche de solutions architecturales soutenables performantes.

Des approches sur la numérisation et la valorisation de l'héritage bâti sont présentes dans le quatrième thème « Patrimoine ». Ces travaux s'intéressent à ce qu'on appelle la modélisation « 3D sémantique » où il s'agit de construire et d'exploiter des modèles 3D de bâtiment ou de villes enrichis d'une connaissance sur les objets représentés. Les deux premières approches illustrent les travaux sur la numérisation et l'exploitation de maquettes de villes avec comme cadre d'étude ceux de la collection des Plans-Reliefs exposés aux Invalides. La troisième approche propose d'exploiter un modèle 3D enrichi pour construire des parcours pédagogiques dans un « jeu sérieux ».

Trois exemples de transferts de travaux de recherche en expériences pédagogiques sont regroupés sous le thème « Pédagogie ». Les travaux présentés illustrent comment la production de connaissances par la recherche est de nature à irriguer la formation de futurs praticiens en proposant de nouveaux outils et de nouvelles méthodes pédagogiques.

Enfin dans le thème « Travail collaboratif » se trouvent trois publications représentatives des travaux réalisés dans le cadre d'une collaboration entre le CRP Henri Tudor du Luxembourg et le MAP-CRAI qui a permis l'encadrement de trois thèses financées par le Luxembourg. Ces travaux portent sur l'étude des pratiques collaboratives autour du projet de conception/construction pour proposer des services logiciels et une multi-visualisation adaptés à chacun des acteurs intervenants dans cette activité collective. Le dernier article présente une approche originale de la prise en compte de la notion de confiance et de sa visualisation dans ce processus collectif.

Afin de permettre à tous d'appréhender plus facilement le contenu de ces recherches rédigées principalement en anglais, chaque thème est présenté par les résumés des articles écrits en français. Vous trouverez également la liste et la description des conférences dans lesquelles ces travaux ont été publiés à la fin de l'ouvrage. Nous avons tenu à garder la forme éditoriale préconisée par les comités d'organisation de chacune des conférences ce qui justifie la présentation non uniforme des différents articles.

Ces cahiers s'adressent à tous ceux, enseignant, chercheur, architecte, ingénieur ou étudiant, qui s'intéressent de loin ou de près aux recherches en architecture numérique et plus particulièrement aux initiatives du laboratoire MAP-CRAI dans ce domaine, en souhaitant que ces premiers cahiers contribueront à la compréhension de ces travaux et pourquoi pas à l'émergence de nouvelles thématiques, initiatives voire vocations.

Nancy, septembre 2013

Gilles Halin
Directeur Scientifique du MAP-CRAI

Environnement

Environnement

Résumé :
L'intégration des données environnementales dans les projets d'architecture est aujourd'hui une nécessité largement reconnue. Le besoin d'estimer la qualité environnementale à différents moments du processus de conception apparaît comme souhaitable pour fiabiliser les choix. La complexité d'une telle estimation provient en partie du fait qu'en fonction de l'avancement du projet, les données de projet évoluent, passant de l'état de non connus à incertains, puis de variables à certains. Pour répondre à cette situation, nous proposerons une méthode et un outil d'estimation environnementale évolutifs. En fonction du contexte du bâtiment en projet (localisation, programme,...) et de l'avancement de la conception (Esquisse, APS,...), notre outil propose un système de valeur coefficientée pour estimer la qualité du projet en cours.

Résumé :
Lumière naturelle et énergie dans les phases initiales du processus de conception architecturale.
L'intégration de la lumière naturelle durant les premières phases du projet peut aider le concepteur à concevoir des bâtiments qui respectent l'environnement et profitent des gains solaires pour répondre aux besoins d'éclairage et d'énergie. Cet article propose une méthode et un outil déclaratif adapté aux phases amont du projet. Cette méthode assiste le concepteur dans l'activité d'intégration de la lumière naturelle et de son impact énergétique dès les premières étapes d'élaboration du projet en considérant les intentions comme information de base. Ces intentions concernent les effets de lumière naturelle, le comportement énergétique ainsi que la configuration spatiale. La méthode proposée traduit les intentions du concepteur en solutions potentielles. Les solutions générées constituent une première matérialisation des intentions du concepteur qui peut se les approprier pour les intégrer progressivement dans son projet.

Résumé :
Eco-modèle. Modélisation d'un outil de conception pour des bâtiments soutenables.
La demande d'informations et d'outils de conception pour aider les architectes à concevoir des bâtiments plus durables est aujourd'hui en pleine expansion. Cette demande conduit à utiliser divers outils d'évaluation écologiques comme outils de soutien au processus de conception. Cependant l'absence d'outils adaptés aux phases précoces de conception, ainsi que les coûts supplémentaires engendrés par les modifications tardives des projets, nous a conduit à proposer un nouvel outil d'aide à l'éco-conception. Ce dernier est basé sur une méthodologie fondée sur des patrons environnementaux ou "Eco-Modèles". Cette méthode invite à utiliser des solutions respectueuses de l'environnement dès les premières esquisses en proposant un certain nombre de micro-solutions types. L'article présente en suite la première version d'un logiciel basé sur cette approche. L'objectif est de permettre aux différents acteurs de l'équipe de conception d'être en mesure de parcourir les informations utiles pour leurs projets et ainsi de collaborer pour optimiser la conception environnementale du bâtiment.

Proposition d'une méthode d'estimation de la qualité environnementale de la conception architecturale

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RÉSUMÉ. L'intégration des données environnementales dans les projets d'architecture est aujourd'hui une nécessité largement reconnue. Le besoin d'estimer la qualité environnementale à différents moments du processus de conception apparaît comme souhaitable pour fiabiliser les choix. La complexité d'une telle estimation provient en partie du fait qu'en fonction de l'avancement du projet, les données de projet évoluent, passant de l'état de non connus à incertains, puis de variables à certains. Pour répondre à cette situation, nous proposerons une méthode et un outil d'estimation environnementale évolutifs. En fonction du contexte du bâtiment en projet (localisation, programme,…) et de l'avancement de la conception (Esquisse, APS,…), notre outil propose un système de valeur coefficientée pour estimer la qualité du projet en cours.
MOTS-CLÉS : Estimation environnementale, processus évolutif, contextualisation, conception architecturale.

Introduction

Les questions environnementales apparaissent aujourd'hui comme des enjeux clés pour l'avenir de notre planète. Le secteur du bâtiment étant responsable, à titre d'exemple, de 43 % de l'énergie consommée et de 25 % des émissions de Gaz à effet de serre, en France (source Ademe), la nécessité d'une prise en considération des questions environnementales dans le monde du bâtiment, de la conception à la construction, n'est donc plus à démontrer (Farel, A & al, 2006).

Les démarches environnementales qui structurent aujourd'hui le secteur du bâtiment font appel à plusieurs méthodes et outils. Les méthodes de certifications (NF démarche HQE, BREEAM,…) visent à sécuriser les maitres d'ouvrage en garantissant un niveau minimum de prestation pour répondre à des objectifs définis. Des outils de simulations (Ecotecte, Pléiades-Comfie,…), d'évaluation (BDM[1]) ou encore de guide (guide des bonnes pratiques de l'Ademe[2], guide pratique « énergétique IDAE en Espagne[3]…) viennent également assister les différents acteurs du bâtiment.

Ces approches présentent l'avantage de favoriser les échanges au sein des acteurs et influencent ainsi les performances environnementales du bâtiment (Cole, 1999). Nous constatons cependant plusieurs limites à ces outils :

– Ils sont généralement peu ou mal adaptés aux phases amont de conception ;
– ils ne prennent pas suffisamment en compte le contexte propre de chaque projet.

Ces méthodes sont généralement utilisées en fin de conception, voire de post-conception (Ding, 2008). La prise en considération de critères essentiellement quantitatifs renforce cette utilisation tardive. En effet, la mesure quantitative, de certains enjeux, ne peut se faire qu'à un stade avancé de la conception ou lorsque le bâtiment est totalement réalisé (par exemple l'infiltrométrie à l'air). Or il n'est plus à démontrer que pour avoir des réponses pertinentes, il est important de considérer les problèmes environnementaux le plus tôt possible dans le processus de conception (Jourda, 2011).

Les limites évoquées ne favorisent donc pas l'émergence de solutions architecturales liées à des choix qui interviennent à l'amont de la conception (positionnement dans le site, volumétrie, orientation, distribution des espaces,…) et qui, de ce fait, ne sont que rarement évalués et donc valorisés. En revanche, les solutions techniques, dont les performances sont plus aisément vérifiables, sont survalorisées et finissent même par définir la qualité voire

1 http://www.polebdm.eu/
2 Http://Ecocitoyens.Ademe.Fr
3 http://www.idae.es

l'exemplarité des bâtiments.

La nature complexe de la conception architecturale perçue soit comme un mécanisme de résolution de problème (Pros, 2000) ou encore comme un processus arborescent (Alexander, 1974) ne facilite pas l'intégration de méthode à cette activité. En effet le caractère non linéaire, peu prévisible et itératif de la conception qui peut s'apparenté à la définition de la « pensée complexe » (principe de dialogue, principe de récursion organisationnelle et principe hologrammatique) de Edgard Morin (Morin, 2005).

L'intégration de méthodes d'aide à la conception environnementale dans un tel processus peut paraître difficile. Le caractère évolutif des questions et réponses, la nécessité d'un point de vue holistique comme la particularité de chaque situation de projet rendent les approches méthodologiques délicates.

Cependant insérer, dans le processus de projet, des points de remise en question (Parthenios, 2008) « environnementale » paraît cependant nécessaire et possible.

Suite à l'analyse des méthodes existantes et de leurs limites et afin de répondre à la complexité de l'estimation de la qualité environnementale de la conception, nous portons une réflexion sur la mise en place d'une méthode d'estimation de la qualité environnementale qui soit adaptée à cette situation.

Notre réponse passe par la mise en place d'un modèle possédant trois caractéristiques :
– un modèle global et qualitatif ;
– un modèle contextualisé ;
– un modèle progressif ;

L'ensemble de ces caractéristiques permet au modèle de mieux s'adapter au processus de conception architecturale. Un modèle global et qualitatif permet une appréhension de l'ensemble des enjeux environnementaux. La contextualisation permet de prendre en compte les singularités de l'édifice en cours de conception et donc la particularité des enjeux environnementaux qui y sont liés. Un modèle progressif s'adapte à l'évolution du processus de conception architecturale en considérant les caractéristiques spécifiques de chacune des étapes qui le constituent (données disponibles, stabilité des informations,…).

Le but de notre proposition est de mieux cibler les enjeux environnementaux pour chaque situation de projet (contexte et processus de conception) et donc d'obtenir une estimation plus fine de la qualité environnementale proposée.

Instrumentation de l'estimation environnementale de la conception

L'instrumentation proposée est celle d'une méthode d'estimation de la qualité environnementale de la conception. Des estimations qualitatives (sur la base d'un référentiel contextualisé et progressif) seront effectuées, à dire d'expert, pendant les phases de conception, et ainsi proposées à l'équipe de conception.

Dans un premier temps, nous présentons la méthode et ses caractéristiques générales (globale et contextualisée). Cette première partie faisant l'objet d'un précédent article restera de l'ordre du résumé (Weissenstein, Bignon, 2010). Dans un second temps, nous nous attarderons sur son caractère dit progressif qui permet entre autres une adaptation au processus de conception.

Une méthode globale et contextualisée

Les caractéristiques essentielles pour le bon fonctionnement d'une évaluation ou d'une estimation environnementale sont la multidimensionnalité, la contextualisation et une visualisation adaptée (Cole, 1999).

Le point de vue multidimensionnel et global nous paraît essentiel pour percevoir l'ensemble des enjeux liés aux mondes de la construction. Nous avons donc mis en place, en nous appuyant sur la littérature « environnementale» et les méthodes existantes, un référentiel composé de quatorze objectifs (impact dans le site, orientation, distribution des espaces,...).Ces derniers sont décomposés, en une soixantaine de critères d'évaluation. Afin de laisser à la méthode un caractère « accessible » (Farel, 2006), nous avons préféré ne pas multiplier les niveaux hiérarchiques.

La contextualisation de la méthode est également essentielle, tous les critères n'ont pas la même importance en fonction du contexte du projet. Par exemple, dans un milieu urbain dense, la notion de nuisance acoustique n'aura pas la même importance que dans un milieu isolé. Nous avons donc mis en place un système de pondération des critères environnementaux qui s'adapte en fonction du contexte du projet.

La visualisation des résultats, de l'estimation, contribue aussi à son bon fonctionnement, là encore la vision globale est à privilégier (Cole, 1999), la représentation graphique adoptée est celle d'un radar. Ce radar est combiné avec un graphique à secteurs (figure 1). Ce couplage permet de visualiser à la foi l'importance engendrée par les pondérations des objectifs, et le profil représentant la performance environnementale. Plus l'angle du secteur est ouvert, plus l'objectif a de l'importance (pour un contexte donné) ; plus le rayon du profil est grand, plus la performance environnementale est bonne.

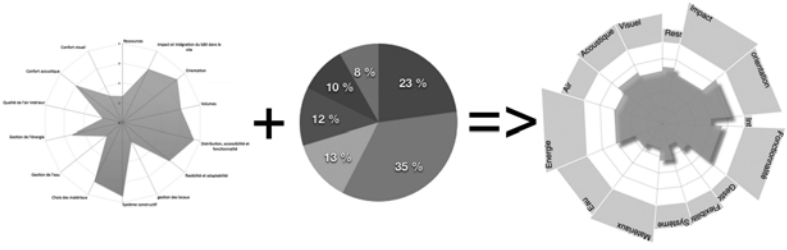

Figure 1. Constitution du profil environnemental.

L'ensemble du référentiel a été soumis auprès de professionnels architectes. Ces confrontations ont permis d'ajuster à la fois les critères et les coefficients de contexte.

Une méthode progressive

L'ensemble des éléments mis en place permet d'avoir un système d'estimation et de visualisation global et contextualisé de la performance environnementale. Cependant, une telle méthode pouvoir être adaptée aux phasages habituels du monde du bâtiment (Farel, 2006), et plus particulièrement à celui de la conception.

En fonction de l'avancement de la conception, les critères d'évaluation n'ont pas la même importance. Par exemple le critère "limiter l'énergie grise des matériaux", dépend de la connaissance des matériaux du projet. Or, dans les premières phases de conception, la totalité de ces matériaux est rarement définie, le critère pourra être évalué que partiellement. En revanche à la fin de la conception, tous les matériaux seront connus et l'appréciation de ce critère pourra être complète. La prise en compte de chaque critère dépendra donc de l'avancement du projet.

La réflexion suivante porte sur l'adaptation de notre méthode au caractère évolutif de la conception. Nous avons opté pour la création d'une estimation adaptable à l'avancement du projet. Si nous connaissons le point de départ (pas de décision définie) de la conception et son point d'arrivée (toutes les décisions définies), le chemin entre les deux états est difficilement prévisible et dépend de nombreux facteurs (conviction du concepteur, habitude de travail...). Il est donc très difficile de proposer un scénario unique d'avancement de tous les projets architecturaux. Il faut donc pouvoir caractériser cet avancement projet par projet.

Pour caractériser les données disponibles lors de l'avancement d'un projet, nous avons procédé en trois étapes. La première a consisté à identifier les données nécessaires pour évaluer chaque critère environnemental. Dans la deuxième étape, nous avons regroupé et organisé ces données nécessaires en "décisions architecturales" pour rationaliser et faciliter l'utilisation de la méthode. La dernière étape s'est attachée à mesurer la répercussion de ces "décisions architecturales" sur les critères environnementaux.

Identification, organisation, et adaptation

L'identification des données nécessaires à l'appréciation de chaque critère s'appuie sur la littérature relative aux enjeux environnementaux. Nous prendrons comme exemple des extraits de la littérature ayant à l'identification du critère "Apport de lumière naturelle suffisant" :

> "[…] intérêt psychophysiologique par le rôle bactéricide de la lumière naturelle et par ses variations selon les heures de la journée. Combinant une température de couleur élevée à un spectre continu dans le domaine visible, sa qualité reste inégalée, même par l'éclairage artificiel le plus performant. Cet aspect est d'autant plus important pour la conception de bureaux où une mauvaise acuité visuelle est source de fatigue oculaire, perte d'attention, maux de tête, mauvaise posture [...] D'une manière générale, l'apport maîtrisé de la lumière naturelle vers les espaces intérieurs favorise le confort visuel des usagers du bâtiment." p 231 (Liébard, Herde, 2006)
>
> " La quantité de lumière captée dans un local dépend de la nature et du type de paroi vitrée, de sa rugosité, de son épaisseur et de son état de propreté. L'aménagement des abords peut aussi créer une barrière à la pénétration rasante du rayonnement d'hiver ou d'été, tout en laissant une large ouverture à la lumière du ciel. Inversement, des surfaces réfléchissantes au sol (dallage, plan d'eau) peuvent contribuer à capter davantage de lumière."p49 (Liébard, Herde 2006)
>
> "Tous les locaux de séjour prolongé doivent bénéficier d'un éclairement naturel satisfaisant par sa qualité et sa quantité.[...] la taille des baies vitrées doit être optimisée en fonction de l'orientation de la façade considérée, des effets de masque éventuels et de la profondeur du local " p 33 (Jourda, 2009).

De ces extraits nous pouvons en déduire que pour évaluer correctement ce critère il est, entre autres, nécessaire de définir les éléments suivants :

– l'orientation du bâtiment et l'implantation du bâtiment ;
– l'aménagement extérieur du bâtiment ;
– le positionnement des fenêtres, leur taille, leur nature, leur proportion, etc. ;
– la nature des revêtements intérieure;
– etc.

Ce travail d'identification a été opéré sur l'ensemble des critères environnementaux afin de définir toutes les données nécessaires pour effectuer l'estimation environnementale.

Nous avons organisé ces données nécessaires en "décisions" architecturales réparties en trois catégories (tableau 1). Une catégorie relative à l'organisation du bâtiment, une catégorie concernant les matériaux, et une dernière concernant les techniques et réseaux.

Tableau 1. Catégories et décisions architecturales

Organisation	**Matériaux**	**Techniques et réseaux**
Positionnement du bâtiment dans le site	Structures	Sanitaire/eaux
Volumétrie du bâtiment	Enveloppes	Chauffage et climatisation
Organisation interne	Partitions	Renouvellement d'air
Aménagement externe	…	…

Chaque décision possède des niveaux de définition en fonction de l'avancement de la conception. Nous avons défini trois niveaux généraux :
– un niveau initial : aucun élément n'est défini ;
– un niveau final : l'ensemble des données de la décision est concrétisé ;
– des niveaux intermédiaires, dont l'ordre est libre et indépendant.

Par exemple, la décision concernant la structure sera composée de quatre niveaux de définition :
– niveau initial : aucune décision ;
– niveau intermédiaire : choix de la nature des matériaux ;
– niveau intermédiaire : choix de la trame ;
– niveau final : mise en œuvre de la structure ;

Une fois la caractérisation des données disponibles effectuée, nous avons proposé une grille qui cadre l'appréciation du critère en fonction de l'avancement du projet. Ce cadrage passe par la définition d'une échelle de notation de chaque critère pour un avancement donné.

L’échelle de notation évolue en fonction des données disponibles. La notation maximale, du critère, dépendra de ces données :
– La note maximale sera de 5 pour un critère aux données complètes ;
– la note maximale sera de 0 pour un critère sans donnée ;
– la note maximale sera comprise en entre 1 et 4 pour un critère aux données partielles.

Les critères seront donc évalués entre 0 et leur notation maximum. Pour une estimation à un moment donné, les critères ne possèderont pas la même échelle d’évaluation.

Visualisation

La représentation graphique adoptée permet la visualisation de ce système évolutif (figure 2). Afin de situer l’avancement du projet, un second profil dit “profil idéal d’avancement” (1) est incorporé au profil d’origine (2).

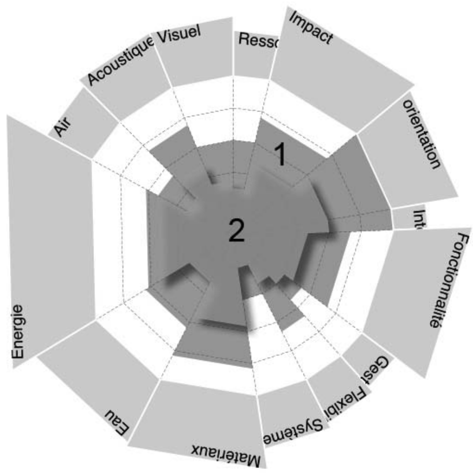

Figure 2. Profil environnemental.

Il présente la notation maximum pouvant être obtenue à un moment donné et donc pour les décisions effectuées. La comparaison des deux profils permet de situer la qualité environnementale d’un projet en cours par rapport à ce projet dit “idéal” à un même état d’avancement.

Outil

La méthode proposée a été implémentée dans un outil numérique « Eco-Profil développé en COCOA dans l'environnement Macintosh. Celui-ci permet de synthétiser et d'automatiser le calcul des coefficients de contexte et des notations maximums en fonction de la situation de conception. Il sert de support aux estimations et à la visualisation des résultats.

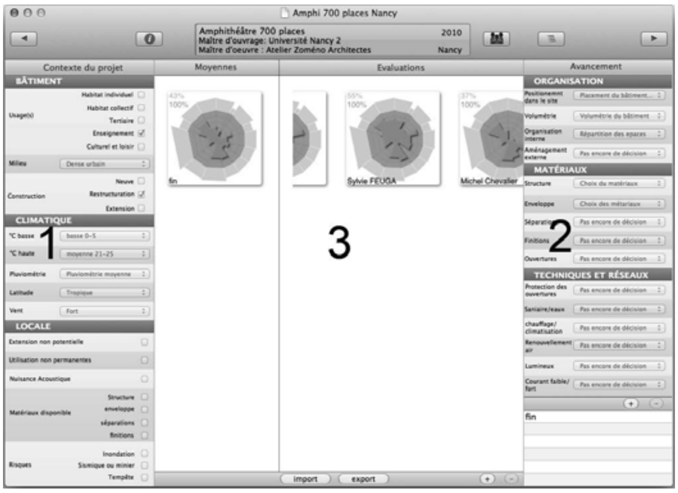

Figure 3. Aperçu de la fenêtre principale de l'outil Eco-profil.

L'outil (figure 3) permet à l'utilisateur une saisie du contexte (1) ainsi que des avancements (2), définissant ainsi le cadre des estimations. Pour chaque état d'avancement défini, une estimation de la qualité environnementale peut être effectuée et visualisée par plusieurs évaluateurs (3).

Une première validation de ce travail sera faite lors de l'estimation, avec la méthode et l'outil développé, des projets des candidats au prix du meilleur projet environnemental proposé par l'association Lorraine Qualité Environnement.

Conclusion

Bien que complexe par son caractère global et labile, la conception architecturale peut être instrumentée par une méthode d'estimation environnementale adaptée. La contextualisation du projet comme la prise en compte de son évolutivité sont des éléments de réponse pour rendre crédible une telle méthode. Cette dernière et l'outil numérique que nous avons développé peuvent être utilisés par le concepteur pour effectuer une auto-appréciation ou par des experts externes à différents moments de la conception. Ils peuvent permettre de guider les choix environnementaux fondamentaux aux moments où ceux-ci sont aisément modifiables par le concepteur et contribuer ainsi à la définition d'une meilleure qualité environnementale propre à chaque projet.

Une expérimentation en court, confronte l'outil et la méthode à des situations de conception. Des protocoles d'estimations, à plusieurs stades d'avancement, sont mis en place dans le cadre de projets éducatifs. Cette expérimentation permettra de mesurer l'intérêt de notre proposition.

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DAYLIGHT AND ENERGY IN THE EARLY PHASE OF ARCHITECTURAL DESIGN PROCESS

A design assistance method using designer's intents

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Abstract. The integration of daylighting from the beginning of the design process can help designers to create buildings that respect their environment, benefit from the solar gain thus giving an answer to illumination and energy needs (Bodart et al, 2002). This paper proposes a declarative assistance method/tool designed for the early design phase. This method assists the designer in integrating the daylight and its energetic impact from the beginning of the architectural design process by means of intents. The intents are related to the daylight, energy and spatial configuration aspects of the architectural project. The method translates the designer's intents into potential solutions. They are the first formal representation of the architect's intents that could be customized and altered during the next architectural design phases.

Keywords. Daylight; energy; early design phase; design support; intents

1. Introduction

The environmental awareness urges the designer to integrate the daylight and its energetic impact into the early phases of the architectural design process. "*Decisions taken rapidly in the early stages of design can have a large impact on the performance of the finished building.*" (Gratia et al, 2001). Several design assistance methods propose to help the designer to realize a better integration of the daylight and the energetic impact in different phases

of the design process. They mostly involve in-depth knowledge without a real integration method and are designed to evaluate the performance of architectural shapes under criteria in relation with daylight and energetic features. This type of method/tool is characterized by the lack of elements that can support the design process during its first steps. The reason is that these engineer's methods/tools are developed to answer needs that are different from the architect's ones. A new generation of prototypical methods propose to assist the architect by integrating architectural knowledge in early design phases. Among these methods the declarative modelling one uses the intents as a main data to establish a real dialogue between the method and the designer. It uses the designer's intents to propose potential solutions.
Our research subscribes to this way and defines a method that must:

- Integrate the daylight and its energetic impact
- Be adapted to the starting phase of the architectural design process
- Allow a real dialogue with the designer

The first part of this paper presents two types of methods integrating the daylight and the energetic aspects. We present the process, the different actor's (person and system) tasks, the manipulated data types and if they answer to our expectations. In the second part, we present the process and the different phases of our assistance method integrating the daylight and its energetic impact by the use of the designer intents.

2. Design assistance methods

Different design methods are developed to assist the designer on the different tasks during the architectural design process. These methods focus on particular domains of the architectural project as the daylight, the energy or acoustics. They take part in the architectural design process by different ways and at different phases. The evaluation of an array of methods allows the identification of two major method classes, the decision support method and the design assistance method.

2.1. DECISION SUPPORT METHODS

This class of methods is designed for engineers and used to realize quantitative evaluations of architectural project features like the energetic, acoustic or daylighting behaviour. They participate during the last phases of the

architectural design process where the evaluations results make sense to validate some designer choices or strategies. (Figure1)
Among these methods the models ones (the modular climate chamber[1], the Heliodon[2], the Scanning Sky Simulator[3]), the simplified calculation methods (LUMcalcul) and the simulation software (Dialux®, Ecotect®, ArchiWizard®).

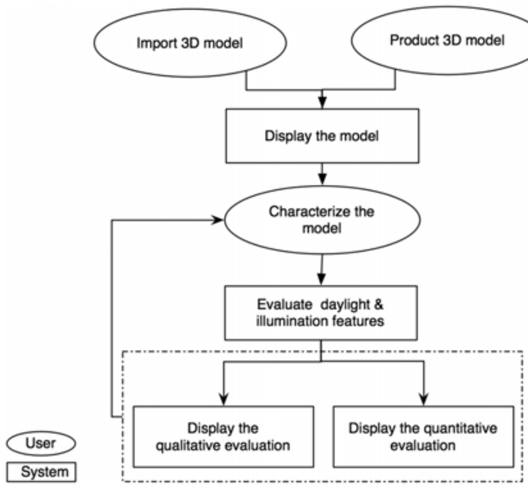

Figure 1.The process of standard support decision method

Dialux® import 3D models of architectural projects from standard CAD systems to test different illumination strategies and evaluate their daylighting or artificial lighting behaviour. These models must be formalized and characterized to make the simulation possible. The user must define the project features, i.e. the orientation, the surfaces characteristics, the light sources. The simulation results concern the quantitative evaluation as the photometrical values (daylight Factor, Illuminance…) and the qualitative ones (photo-realistic representation of the generated daylighting effects).
The decision support methods can hardly be used during the early phases of the architectural design process because the designer is not able to define the different features characterizing the project. Indeed, Lawson (Lawson, 2006) defines the "moving activity" characterizing the starting phases of the design process where the project is still on the drawing board. The "moving activity" integrates the designer intents generation and transformation to propose potential solutions. But, these support decision methods are not able to support this design activity.

2.2. ASSISTANCE DESIGN METHODS

Different research groups in architectural domain propose a new generation of assistance design methods linking the popular three-dimensional CAD modeller (Rhinoceros®, Sketchup®) with advanced daylight simulation tool (Radiance, Daysim). It makes possible the evaluation and the validation of a large number of designs variant at the early stages of the design process. They produce a quick feedback integrated on the project development. The DIVA (Lagios et al, 2010) workflow integrates on Rhinoceros® single and multiple evaluation of the daylight behaviour of schematic design configuration. LightSolve (Andersen et al, 2008) is a plugin for Sketchup® used to analyse and to visualise the daylighting effects from different viewpoints of the project and under various sky conditions.

Another type of methods integrates some architectural knowledge to assist the design process. They use the declarative modelling method using designer's intents to generate potential solutions. The intents represent the architect's choices or the design constraints concerning a particular aspect of the project creation. They are described using architectural terms (Lassance, 1999). This method is used in different architectural assistance method designed to create real dialogue between the designer and the method. Three actors (system, person) are participating in the declarative modelling process: the "user", the "interface" and the "system". The declarative process is organized in three phases; the "describing", the "generating" and "assessing" phases. (Figure2)

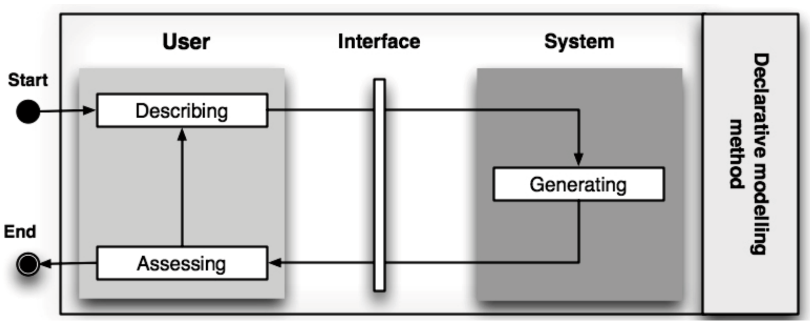

Figure 2.The declarative modelling process

On the "describing" phase, the "user" describes his intents using an architectural language in relation with a particular aspect of the architectural project, like the daylight atmospheres for instance. During the generation phase, the "system" translates the designer's intents into geometrical constraints to generate solutions. The "user" participates also in the "assessing" phase dur-

ing which he evaluates the generated results. Following that, he can select solutions that are corresponding to his intents.
This method is used to assist different tasks of the architectural design project. With the WordsEye (www.wordseye.com) project the user gives the description of a desired 3D model, expressed in a natural language. A very important database is used to translate the sentences in a set of constraints and generate 3D models. (Figure3)

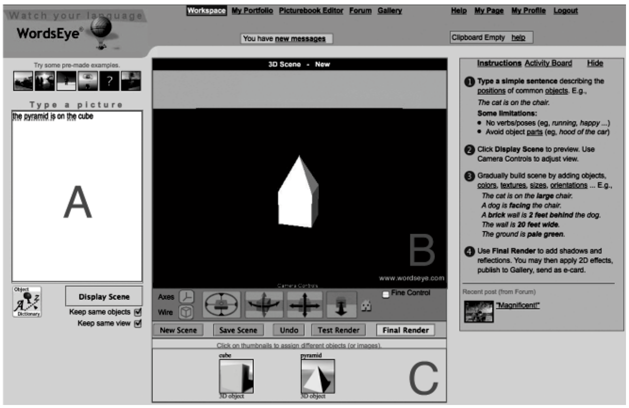

Figure 3.WordsEye modelling process, (A) describe the scene, (B) show the 3D scene, (C) show the 3D scene components.

Faucher (Faucher, 2000) proposes a declarative method integrating the designer intents related to sunlight, visibility and urban regulation. It uses an architectural knowledge base that translates the described intents into constraints to make the generation of potential solutions possible. The method proposes potential geometrical configuration of sunscreens or building shape generating the described intents. (Figure 4-5)

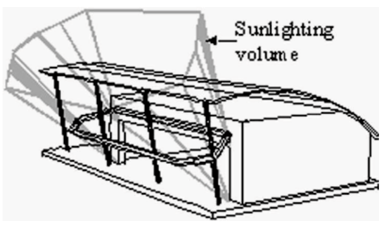

Figure 4.Proposed solution to the daylight intent "The front of the project must be sunlit in the middle of the day in winter".

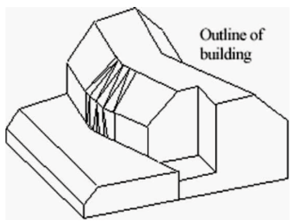

Figure 5.Proposed solution to the urban and visibility intent "The building must be included in the maximal volume of the site".

Leso-Dial (Paule and Scartezzini, 1997) is a declarative tool allowing the designer to describe a spatial configuration using an architectural language, to evaluate the daylighting results. An expert diagnosis allows architect to point out the possible weak points of their design. (Figure 6)

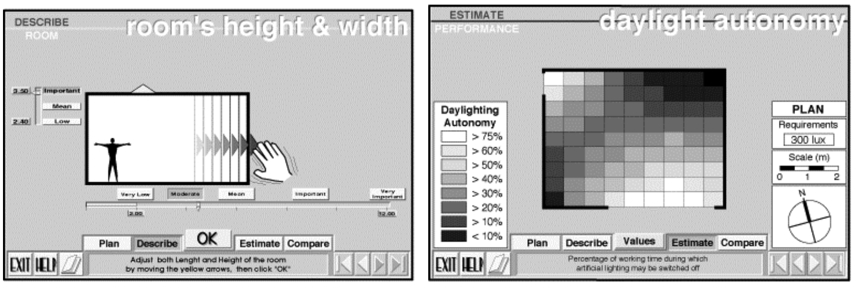

Figure 6.Examples of graphic input and output on Leso-Dial

3. Proposed design support method integrating the daylight and its energetic impact

We propose a declarative design support method using the architect's intents to generate potential solutions. The intents are the representation of the daylighting effects or atmospheres that the architect would like to create. The main feature of this method, that makes it different from the other assistance methods, is the integration of architectural knowledge linked to the daylight, spatial and energetic domain of the project. This knowledge will be used as a reference to translate the designer intents into potential solutions.
The solutions are a formal representation of the architect's intents. The method allows the evaluation of the energetic behaviour of the proposed solutions that constitutes another selection criterion.

3.1. THE METHOD PROCESS

In our declarative modelling method six actors are participating in the process; the "designer", the "interface" and four different "systems". Two external "systems" participate in the method process, which are the "simulation system" and the "C.A.Drafting system". Every actor realizes different tasks, which are successively organized to constitute the method process. First, the "interface" presents different intents imported from the "intents database". Then, the "designer" chooses intents that the "generating system" will integrate to generate potential solutions. After that, the "Simulation system" evaluates the qualitative and the quantitative features and the energetic impact of the proposed solutions. The "interface" presents the evaluation results. The "designer" assesses the results and selects the solution(s) that is (are) corresponding to its intents. (Figure 7)

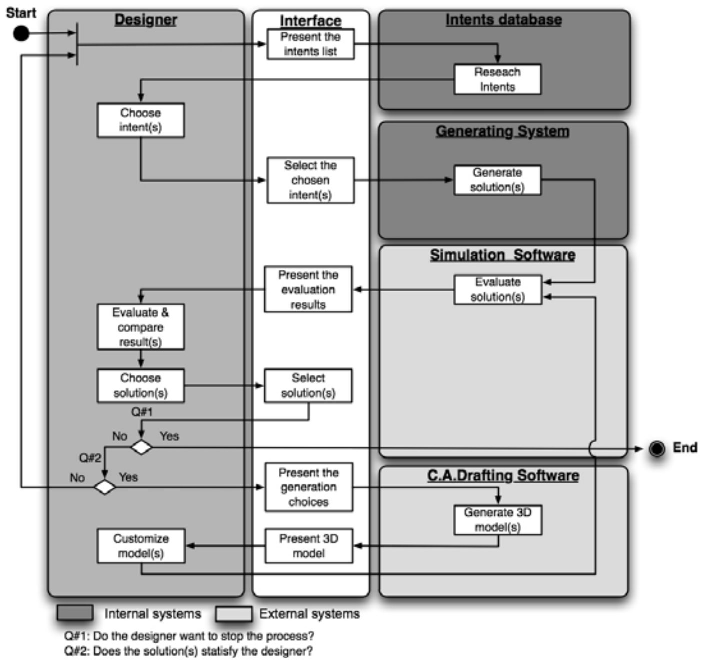

Figure 7.The proposed method process

Finally, the designer can choose to stop or to continue the process. If he chooses to continue, two cases are proposed:

- If he is satisfied with the generation results, he can generate 3D model(s) that will be further customized and evaluated.
- If he is not satisfied with the generation results, the "designer" can restart the whole process and select other intents

3.2. THE INPUT DATA TYPE

The main data used in the proposed method is the designer's intents. Faucher (Faucher, 2000) defines them as "*a conceptual expression of constraints having an influence on the project*". They are described using an architectural language and characterized using the concept of indices introduced by Mudri (Mudri, 1996) who proposes an evaluation method of the daylight and energetic behaviour of project sketches. The indices could have a symbolic value that represents an aesthetic quality or a numerical value as dimension, reflexion factor (Marin, 2008). We use these indices to structure an intents database that participates in the system process. (Figure 8)

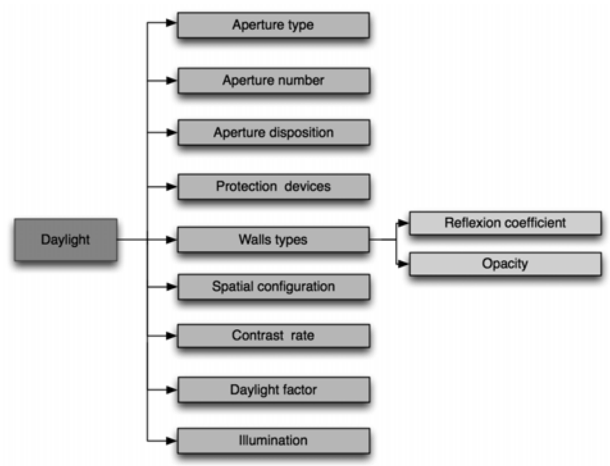

Figure 8 .The lists of indices characterizing the daylight intents

The intents are graphically represented by expressive icons that create a real dialogue between the designer and the system. (Figure 9)

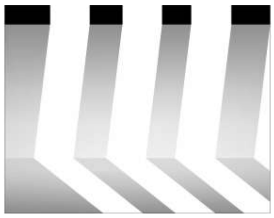

Figure 9.Graphical representation of the daylight intent "Sunspots" (www.audience.cerma.archi.fr)

3.3. THE OUTPUT DATA TYPE

The proposed method considers the architectural project as a set of spatial units because of its complexity. A spatial unit is defined as the smaller part of the project. So, the generated solutions will be presented as a spatial unit creating a particular daylight effect or atmosphere. These cases include all the features of the architectural project. The objective of such a method consists in assisting the architect to take into account daylight effects and its energetic impact through the manipulation and the transformation of these formal cases. (Figure 10)

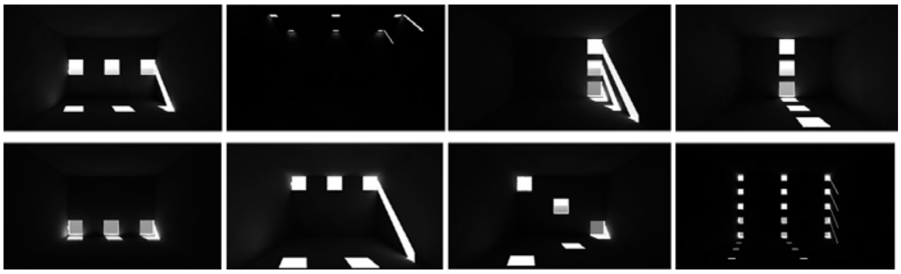

Figure 10.Examples of generated solutions

The evaluation of the energetic behaviour of the proposed solutions helps the designer to integrate this aspect in his architectural design process. The different aspects influencing the energetic impact will be evaluated by the use of indices. These indices were identified and selected because they are influencing the energetic behaviour of the architectural project.

4. Conclusion

This paper presents the first part of our research work. It proposes a declarative method to assist the designer during the early phases of the architectural design process. The only data used is the designer's intents related to the daylight atmosphere. The designer intents are characterized through the use of the concept of indices. The method generates potential solutions that are the formal representation of the designer intent's. An evaluation system is integrated to help the architect to make possible the interaction between the design choices and their energetic impact. The different input and output data are graphically represented to create a dialogue between the method and the user.

During the next step of our research, we will try to detail the different parts of the proposed method as the structure of the intents database and the generating process to develop a prototype. The objective is to evaluate the participation of this method in the architectural design process and its ability to help the architect to integrate the daylight and its energetic impact on the design process.

5. Endnotes

1. The Modular Climate Chamber consists of light elements and insulating modules of 120 cm2 which allow the construction of different simple or multiple volumes, inter-connected or not, for diverse studies regarding the indoor environment. The chamber is equipped with a double-flux air conditioning unit of 1000 m^3/h that allows heating, cooling and air humidification.
2. The Heliodon is used to examine how direct sunlight interacts with an architect's building design.
3. The scanning Sky Simulator developed at LESO-PB, used as a basis for several other sky simulators, allows accurate reproduction of the luminance distributions of every type of sky. It can be used for diffuse light measurements within building scale models for any time of a year and any location and is thus a precious tool for the testing of innovative architectural solutions and daylighting systems.

6. Acknowledgements

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Eco-Models

Modeling of a digital tool to design sustainable buildings

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Abstract. The demand for up to date information and design 'tools' to help architects design more sustainable buildings is rapidly expanding. This demand has led to use various ecological assessment tools as support tools for the design process. The absence of adequate tools which contribute to early stages, as well as the additional costs of tardy modifications, has led us to propose an eco-design support tool. This tool is based on a methodology named "Eco-Model (EM) Method" that focuses on the ecological approaches of a building. This method proposes to consider environmental friendly solutions from the first sketches by proposing a number of micro-solutions, called here Eco-Model or "EM". Subsequently, the study presents the first contour of software based on an EM approach. Thus, the various actors of the design team will be able to browse the useful information for their green projects and so collaborate to optimize the building design.

Keywords: Eco-Models: sustainable buildings; design support.

Introduction and context

The context in which environmental design happens is complex. This complexity is related to a large quantity of operations and impacts to take into consideration. Any object of design cannot be concerned as one isolated object. It should be apprehended from various points of view to reduce the risk of disregarding possible environmental impacts. The design team has to cope with problems containing a high number of variables. The combination of such variables can probably give billions of possible solutions. Even if it's possible to easily discard a great number of those solutions using "common sense" (feasibility, economy, use, etc.), it is also possible to use a method to quickly choose the most satisfactory solutions to explore.

In this particular context, a sustainable building, being a result of environmental design, should be as integrated as possible with its environment. This means that it should be water conserving, non-toxic, and energy efficient, with high-quality spaces and recycled materials and also to propose long-term solutions for large part of resource and emission problems. This integrity requires a continual adjustment of solutions with their contexts, all along the design process.

In recent years, energy saving and environmental optimization are crucial issues in building design. Several professionals and academics propose to re-evaluate the way that buildings are designed and produced (Metallinou, 2006). This is why this subject has been treated widely in the literature through many approaches, such as multi-objective optimization, ranking methods, index-based methods, and other quantitative methods like cost–benefit analysis. But the majority of these approaches evaluate only the finished building design or at least the advanced stage of design. However, environmental building assessment methods are more useful during the design stage when any impairment for the pre-design criteria can be assessed and incorporated at design development (Ding, 2008). For this reason various ecological evaluation tools are improvised and used in many cases as design support tools (Cole, 1999). “Rating system provides an effective framework for assessing building environmental performance… as it can be used as a design tool…; it can also be used as a management tool…” (Castro-Lacourture, 2009). This situation demonstrates the absence of adequate tools that are indicated in the early stages of building projects before anything be completed.

This research evaluates existing approaches to disclose environmental knowledge and approaches to provide design support in design processes. This evaluation, along with the increasing request of this type of tools and the additional costs of evaluation induced by the design of green buildings, led us to propose an eco-design support tool focused on ecological approaches of a building project. Particular attention is given to energy aspects in order to improve the energy-saving potential of buildings. Our research is implemented in three phases: first, the proposition and identification of the method of “Eco-Model” or “EM”; second, solution modelling and relations study in the context of building design, and finally, the application of this method digitally. We think that using the EM method is relevant and provides a better solution than other approaches.

State of the art

Due to recent environmental, social and economical crises, various norms, factors and standards are defined by government's sustainable development strategies. Such legislations have led to the rapid increase of the number of low environmental impact or 'green' buildings constructed. Consequently, the demand for up to date information, guidance and “design tools” to help property professionals procure greener buildings also continues to grow (Shiers, 2006).

On the subject of design tools, there is a clear distinction between what reveals from the “proposal” or the possible solution and what concerns the “evaluation” of the proposal. Most of present tools and methods take evaluation into consideration to respond at this information demand with post-evaluations, as well as pre-evaluation and predictions.

Concerning the proposition aid tools and methods, we can find for example the shape grammars with the generative type of tools. We can also mention to creation aid methods, like as TRIZ (russian acronym for Theory of Inventive Problem Solving), which are based on the basis for creative innovations that advance technology and reduce time to market. These types of tools are less operational in the architectural field. The reference based systems seems to be more useful to help solution proposition in a design process. The numerous applications of this approach prove its usefulness. Goldschmidt (1995) in visual display for design explains the importance of analogy and databases of visual images in an architectural design process. Scaletsky (2005) argues the importance of references and the eventual role that they can have in an early stage of architectural design. We think that the efficiency of case based design or reference based design approaches is to re-use anterior solutions in the analogical mechanisms.

Regarding the evaluation aid approaches, we can mention to the “HQE” in France is one of these approaches. This is a building certification which takes into consideration environmental issues during construction operations. It proposes 14 targets to respond at eco-construction, comfort, eco-management, and health.

Also, “high energy efficiency” is another approach created to label building efficiency in five categories: HPE (High energy efficiency), THPE (Very High energy efficiency), HPE-Renewable energies, THPE-Renewable energies, BBC (Building with low energy consumption).

Many building designers and property professionals do not use environmental tools on all projects because of time considerations and the disruption caused by having to take an 'extra step' in the design and specification process. (Shiers, 2006)

The pre-evaluation and predictions approach is intended to evaluate design performance during the conception stage. Here, an example of a tool is “equer” (IZUBA)1. It is a prediction tool to evaluate environmental impacts before the final concept. However, it doesn’t propose solutions for design aspects. The ECOTECT software is another example of prediction tools. Aimed primarily at architects, this software optimizes a relatively simple and intuitive 3D modeling throughout a vast range of features, like as shading design, solar analysis, acoustic analysis, thermal analysis, ventilation & air flow, resource management. Multiple result comparisons should be done throughout the design process. Its efficiency is better when analyzing a design object from various points of view and at the early stage of design. For example, a new window can be added in order to see its effect on day lighting, thermal response and overall building costs (Roberts et al., 2001). However, this approach seems to cause many drawbacks during the design process because, firstly, it needs to be developed to an extent of producing 3D models, and second, because it is based in trial and error to achieve the appropriate results.

In the evolution of the classical design process, knowledge about efficacy and integrity of choices and decision impacts increase throughout the design process, but on the other hand, liberty of changing and decision making decreases and becomes increasingly expensive and annoying. So we think that it is better to have a digital tool that steps in the front-end stage of a design process. This tool should be able to enlarge environmental-architectural knowledge to help designers produce more innovative environmental projects. Our research, based on the aforesaid, proposes an approach named “Eco-models method”.

Eco-Models Method

During the first phase, this research proposes a methodology to consider environmentally friendly solutions from the first stages of building projects. This approach could be addressed by proposing a number of energetic micro-solutions, called here Eco-Model or “EM”. An EM forms a solution or is a quality-approved form-solution, able to be re-used in an efficient way. Various technical aspects and criteria for achieving a green building project are discussed in this phase.

The various examples of vernacular architecture, conventional architecture and architecture in project are studied to identify EM. Figure 1 presents a number of identified EM. throughout these three kinds of projects.

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1 IZUBA énergies, Développement : Renaud MIKOLASEK, Thierry Salomon, Stéphane BEDEL http://www.izuba.fr/equer.htm

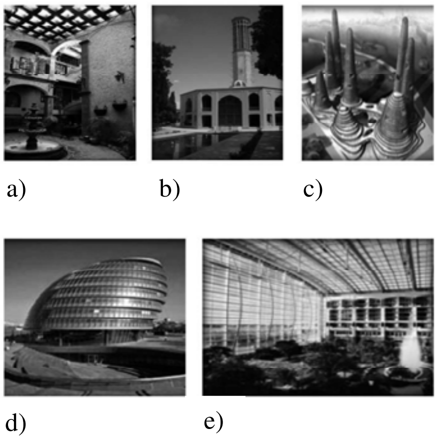


Figure 1
Example of identified EM. from different architectural projects: a) "PATIO" from Posada las Flores in Loreto, b) "WIND CATCHER" from Dolatabad Garden in Yazd, c) "SUSPENDED GARDEN" from futuristic city in Korea, d) "CIRCULAR FORM" from London town hall, e) "ATRIUM" from Gaylord National Resort.

The proposed method is based on the "pattern language" approach, defined by Alexander (1977). Christopher Alexander and his team have defined close to two hundred urban, architectural and construction patterns. Any pattern was presented with a name, a problem and a solution. Then, they have implemented these patterns in a relational system to produce a patterns language. This approach is both used in architecture and in data processing.

The Eco-Models method encourages building owners, architects, engineers, and design professionals to build by advanced knowledge and innovation in the sustainable building industry.

The result of this phase is the identification and definition of different ecological solutions for sustainable projects. A solution feasibility study is done with relevant literature and illustrative building examples. The literature review ensures scientific exactness of solutions and examples to eliminate the implementation weaknesses of the theoretical approaches in real contexts. Afterward, EM. are materialized by an image library and also through the development of use-case scenarios.

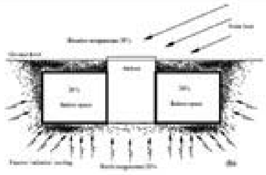
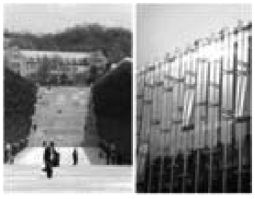
EM 1
Underground architecture

Information Problem: Temperature difference Solution: Use of the inertia of ground
Exemples    N°1- L'Université d'Ewha (Corée du Sud) · N°2- Parc Vulcania :Une architecture aux 3/4 souterraine · N° 3- Canadian War Museum (2002-2005), Ottawa, Canada
HQE Target C4- Energy operating, C9- Acoustic comfort **(inclusion)** C10- Visual comfort, C13- Sanitary quality of air **(exclusion)** C1- Relation of building with its immediate environment **(cooperation)**
Actors Research department - Architect- Heat engineer- Civil engineer- Soil mechanical engineer
Physical parts Equipment, Partition and access, Structure, Adaptation
Spaces External access, Interior yard, Circulation, Roof garden, Sanitary spaces
Others EM Agriculture soil saving **(Inclusion),** Natural light source, Open space at south **(Exclusion)** Atrium **(cooperation)**

Figure 2
EM visualization

Such as case-based design aid for architecture (CBDA) (Domeshek and Kolodner, 1992), the importance of EM models is the usefulness of past experiences during conceptual design. Conceptual design is the very earliest stage of design, during which the main tasks are analyzing the problem and forming initial commitments towards a solution. Providing easy access to descriptions and evaluations of previous designs (e.g. existing buildings, with their strong and weak points) would be a major aid in those tasks.

Eco-Models Tank

In the second phase, a demonstration of relations and impacts of choosing any EM is done in an “Eco-Models Tank”. An “Eco-Models Tank” is a database of architectural references that aims is to highlight "best practices" in ecological project design.

In fact, an Eco-Models Tank is a data base in development that saves all information about solution chosen as an EM and its needs and efficiencies. It is in this phase that we re-evaluate environmental advantages and limits of any EM rather than HQE. This re-evaluation can help us to better define if the solution responds to our own environmental needs from an EM or not. Without any doubt, this relational re-evaluation leads us to an environmental comparison of different EM. and facilitates choosing the solutions. It is what we need to find the better solution in the complex context of environmental building design.

In the Eco-Models Tank, some of the EM. concerned data is described by images and relation diagrams (using UML) from five points of view:

- the building concerned physical parts to address the difficulty level of materializing each EM,
- the involved actors to achieve the EM solution decision and design,
- each EM high environmental qualities, in the French environmental building construction reference ("HQE"),
- the necessary architectural spaces to design,
- the relation between different EM.

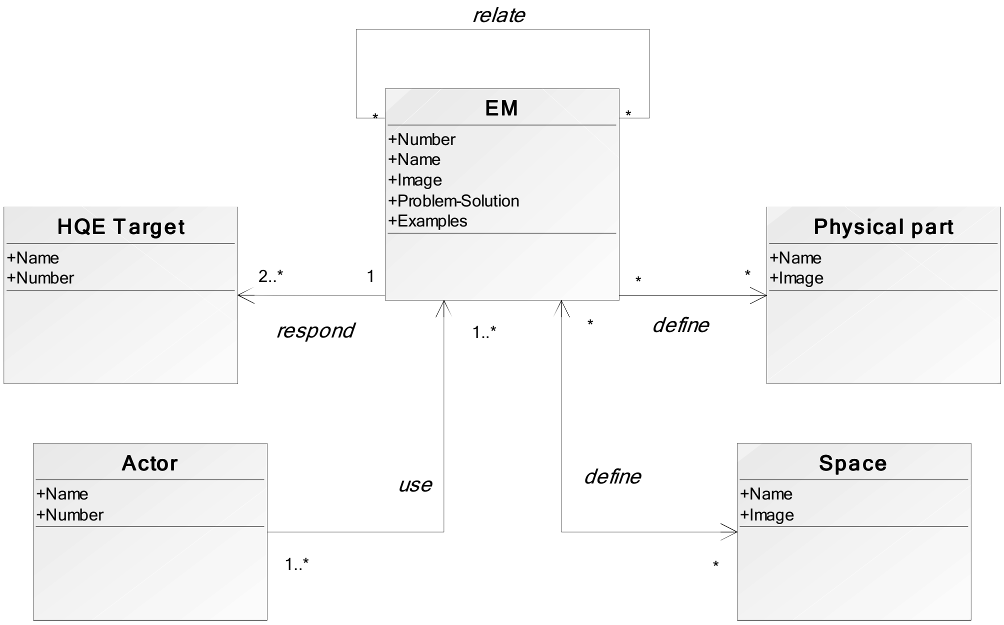


Figure 3
Class diagram of the points of view of an EM information

The relations between EM. can help users to better understand any EM. Like as in the linguistic domain that words give the "context" that allows a reader to make an educated guess about the meaning of an unfamiliar word in the sentence, in the pattern language methodology, any EM which is no familiar to a designer can give meaning from other EM. in relation with it by a natural language grammar (using NIAM: Natural language Information Analysis Method)

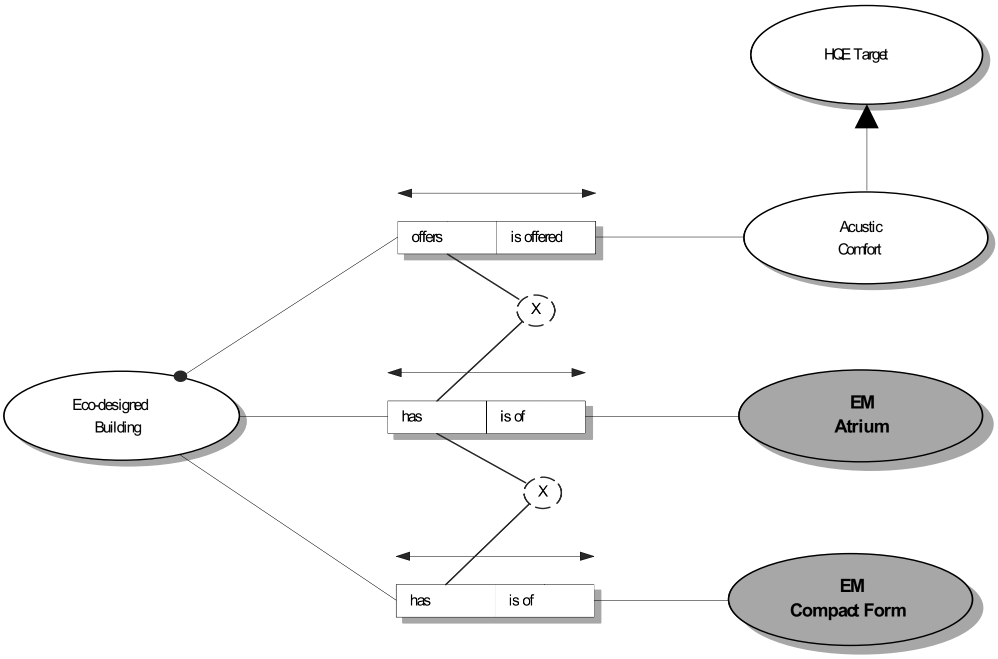


Figure 4
Exclusion relation between two EM, also between an EM and a HQE target

The relations between different EM. could be inclusion, exclusion or cooperation. An inclusion relation between EM. means that using an EM conducts us to use another EM too. An exclusion relation means the impossibility or difficulty to solve for using simultaneously two particular EM. Finally, a cooperation relation is when one or more EM. could satisfy a common requirement. This relational network can simplify the choice of adapted solutions within different situations.

In addition, analyzing EM from five different relational views reduces the risk of believing that the indexed solutions are viable in all situations. This Eco-Models Tank simplifies navigation in an EMs catalogue, presenting various solutions to environmental requirements, allowing the design team a better formulation of its needs and to build their own “choice space” regarding their design context.

Digital tool for eco-design

Subsequently, the study presents a first prototype of the EM-approach based software. To simplify the consultation of this data base (Eco-Models Tank), a digital support is developed. Thus the various actors of the building project design will be able to navigate and find useful information for theirs green building projects. This possibility to define several scenarios helps the design team to evaluate in real-time the impact of its choices in terms of ecological projects management. Finally, this digital support could be adapted to the technical evolutions, architectural and data processing possibilities.

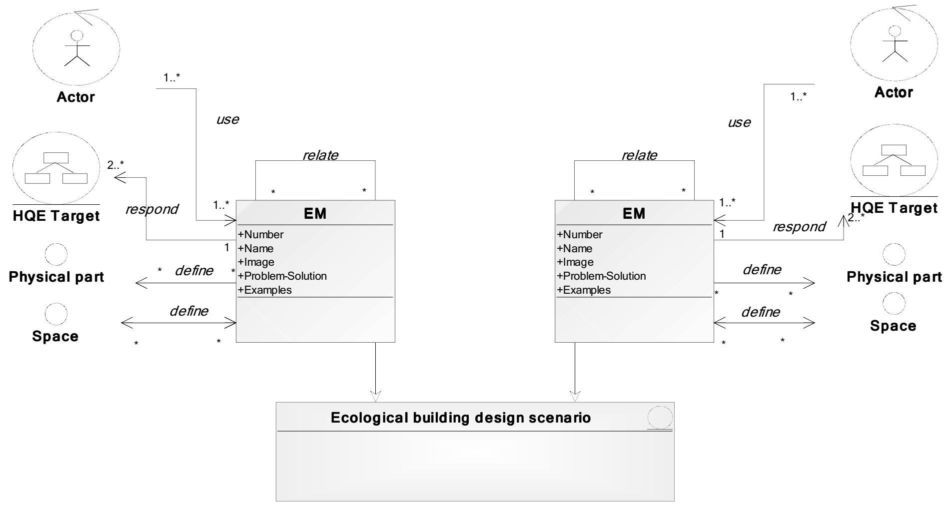


Figure 5
Schematic representation of the scenario modeling tool

Conclusion and perspective

This paper describes the Eco-Models method that can help a design team to find better solutions for their problems using a digital support. The main feature of this tool is the ability to store, share and exchange knowledge through its EM. data base.

This work doesn't focus on problem modeling but in solution modeling. One of our perspectives is to test our proposal on several green building project designs. A tool test and an evaluation of this tool in a real situation are envisaged.

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Matériau et construction

Matériau et construction

Résumé :
Les travaux présentés dans cet article portent sur l'optimisation de structures élaborée à partir d'éléments irréguliers en bois. Qu'ils soient issus du démontage de bâtiments ou directement produits par l'activité forestière sans transformation industrielle, ces éléments de ressource présentent chacun des caractéristiques différenciées et vont constituer une base de matériaux disponibles pour la structure. On se place là dans une logique environnementale où l'objectif est de valoriser la matière première qu'est le bois dans son état d'origine. Pour cela, cette ressource est modélisée puis mise en œuvre au moyen d'algorithmes répondant à des intentions architecturales. Ce principe de construction aboutit au développement d'un outil numérique de conception architectural dans l'environnement Rhinoceros- Grasshopper. La complexité de la conception induite par l'usage de composants sources non-standards trouve une résolution dans un algorithme ayant la capacité à gérer des géométries aléatoires.

Résumé :
Planification collaborative de la construction : vers une visualisation 4D adaptée aux besoins des praticiens.
La gestion des interventions des différents acteurs pendant la phase de construction est un problème récurrent dans le secteur de la construction. C'est en partie la conséquence de la multiplicité des intervenants et la nécessité de gérer les interfaces pour une planification et une coordination des tâches efficace. La technologie CAO 4D apparaît comme une approche innovante pour aborder ces problèmes. Mais l'utilisation de la 4D pour assister le travail collaboratif n'est pas suffisamment adaptée aux besoins du secteur. Cet article propose une taxonomie pour décrire des vues utilisateur adaptées et une méthode dédiée à la conception de vues métiers permettant : d'identifier les tâches métiers (usages) relativement aux rôles des différents utilisateurs, d'offrir des services adaptés à ces différents usages, et de suggérer des modes de visualisation correspondant à chacun des usages en exploitant notre modèle de visualisation. A l'aide d'un cas d'étude, orienté sur la gestion des interfaces entre les ouvrages, nous formalisons le processus collaboratif afin d'identifier les usages de chacun des intervenants impliqués dans la planification du processus collaboratif de la construction. Enfin, nous suggérons des combinaisons de modes de visualisation adaptés à chacune des utilisations afin d'obtenir des compositions de vues pour chacun des intervenants.

Résumé :
Géométrie, conception et construction. Un modèle paramétrique pour la construction de structures en bois non-standards.
La conception architecturale est confrontée à un renouvellement du vocabulaire formel au regard des avancements des techniques numériques. Mais les récents progrès dans la représentation numérique et la description géométrique de la forme architecturale suscitent de plus en plus de questions en ce qui concerne sa matérialisation. Les contraintes de construction, d'assemblage et de mise en œuvre sont des données nécessaires pour rationaliser les modèles géométriques. Cet article présente le cadre d'une activité de recherche visant à élaborer un outil capable de transformer la description géométrique d'une forme non-standard en une géométrie constructive.

Génération de structures non-standards au moyen d'éléments natifs irréguliers en bois

Elaboration d'un outil numérique de conception architecturale

Vincent Monier[1], Gilles Duchanois[2], Jean-Claude Bignon[2]

[1]ENTPE Lyon, [2]MAP/CRAI ENSA Nancy

RÉSUMÉ. Les travaux présentés dans cet article portent sur l'optimisation de structures élaborée à partir d'éléments irréguliers en bois. Qu'ils soient issus du démontage de bâtiments ou directement produits par l'activité forestière sans transformation industrielle, ces éléments de ressource présentent chacun des caractéristiques différenciées et vont constituer la base de matériaux disponibles pour la structure. On se place là dans une logique environnementale où l'objectif est de valoriser la matière première qu'est le bois dans son état d'origine. Pour cela, cette ressource est modélisée puis mise en œuvre au moyen d'algorithmes répondant à des intentions architecturales. Ce principe de construction aboutit au développement d'un outil numérique de conception architectural dans l'environnement Rhinoceros-Grasshopper. La complexité de la conception induite par l'usage de composants sources non-standards trouve une résolution dans un algorithme ayant la capacité à gérer des géométries aléatoires.

MOTS-CLÉS : Architecture Non-Standard, Numérique, Environnement, Bois, Structure.

1 Introduction

11 Contexte

Le développement de l'imagerie numérique a introduit une rupture forte dans l'approche morphologique architecturale. Plus qu'un simple dispositif de « digitalisation » de la représentation traditionnelle, la modélisation numérique a induit une transformation du vocabulaire formel et de la pensée architecturale en « guidant » largement les autres facteurs de forme que sont l'usage, le lieu ou la technique.

Plusieurs auteurs ont vu dans cette surdétermination de la forme par la figuration l'expression d'une nouvelle utopie ; après l'architecture de papier, l'architecture du pixel.

L'architecture dite « numérique » y est vue comme une aventure « plasticienne » à l'image des nombreuses propositions qui jalonnent l'histoire de la pensée utopique, du projet de Cénotaphe d'Etienne Louis Boullée à la pyramide de Shimizu.

Parmi les critiques émises, plusieurs propos reposent sur l'idée qu'une liberté supposée de la forme dessinée introduirait une complexité des propositions les rendant difficilement constructibles. Il faut pourtant convenir que depuis la construction du musée Guggenheim de « Bilbao » la critique de la non-faisabilité est aujourd'hui de plus en plus sans fondement. Il semblerait même que les nouvelles topologies proposées rentrent en phase avec le contexte changeant de la matérialisation et de l'industrialisation en architecture.

L'évolution des matériaux (le lamibois, le ductal, les verres athermiques, les polymères, les tissus 3D…) et plus encore le développement du numérique dans la fabrication (découpe, assemblage) comme dans la mise en œuvre (positionnement) semblent devoir apporter des réponses crédibles aux architectures de l'ère digitale.

De nouvelles technicités émergent en accord avec les nouvelles morphologies. Elles déplacent les questions traditionnelles de la complexité forme/structure en redessinant des passerelles pour passer du pensable au possible. L'octet fait figure de Plus Petit Multiple Commun entre la géométrie des formes digitales et l'univers de la (pré)fabrication avancée de composants.

Le modèle sériel fondé sur l'idée que l'architecture doit s'exprimer dans la répétition à l'identique d'éléments pour atteindre l'efficience technique a dominé la pensée architecturale et constructive depuis près d'un siècle. Mais il n'est plus aujourd'hui le seul crédible.

Le concept de non-standard emprunté aux mathématiques de l'infinitésimal semble devoir décrire cette union entre des formes non régulières et des modes de fabrication capable de produire des composants tous différents en utilisant des machines à commandes numériques.

De nouveaux paradigmes émergent comme celui de « new structuralism » [Oxman 2010] qui permet de redonner une valeur première à l'approche structurale dans la définition de la forme.

Il reste vrai cependant que beaucoup d'approches centrées sur les questions précédentes restent en marge d'un autre grand champ de questionnement qui est celui des approches environnementales. Le High-tech et le Low-Tech seraient-ils incompatibles ?

12 Démarche adoptée

Dans le présent article nous souhaitons intégrer l'approche architecturale, structurale et environnementale dans une même démarche. Notre travail de recherche vise à proposer un modèle et un outil de conception de forme et de structure non standard faisant appel à une ressource en matériaux issus du démontage de bâtiments ou d'éléments bruts de type tronc ou branchage. Il s'agit de maximiser l'emploi de ressources disponibles en l'état en diminuant la quantité de matière perdue et l'énergie consommée dans la transformation.

L'emploi d'éléments faiblement transformés apparaît aujourd'hui comme un enjeu non négligeable dans le cadre des approches soutenables. Cependant cette position se traduit par une complexité accrue de la conception voire de la réalisation des ouvrages. Les éléments faiblement transformés ont des irrégularités de forme, de dimensions et de comportement mécanique qui requiert une modélisation capable de fournir les particularités de chaque élément constitutif de la ressource. La définition de ce modèle paramétrique constitue le deuxième point de cet article. Le modèle développé est adaptable aux éléments issus du démontage d'ouvrages présentant des caractéristiques géométriques relativement simples (solives, charpente…) comme aux éléments ramifiés de type branchages courbes. Parallèlement, la technique de mise en œuvre de ces éléments de ressource a été développée sous la forme d'un algorithme. Les modèles des éléments de ressource ainsi que les intentions architecturales du concepteur constituent les données d'entrée de l'algorithme. L'algorithme de génération de la structure fait l'objet du troisième point de cet article.

Cette démarche constructive basée sur la ressource disponible pour élever des structures est développée dans un premier temps sur le plan logique, affranchie de tout système de programmation. Ces recherches ont abouti au développement d'un outil numérique de conception architecturale dans l'interface Grasshopper de Rhinoceros. Cet espace de travail a été retenu pour l'interactivité aisée qu'il propose pour un concepteur-utilisateur ainsi que pour le caractère modulable du programme une fois fini.

L'outil vise à faciliter l'incorporation du matériau bois dès les premières esquisses du projet en permettant une exploration formelle et structurelle conditionnée par les ressources disponibles.

L'échelle de construction envisagée dépend en partie des dimensions des éléments de ressource disponibles. Toutefois nous pensons pouvoir générer dans un premier temps des structures de type dôme de plusieurs mètres de haut dont la portée reste à définir.

13 Etat de l'Art

L'approche des structures « non-standards » et plus généralement du « new-structuralism » fait aujourd'hui l'objet de nombreux travaux [Oxman 2010]. L'objectif de ces travaux vise à développer de nouveaux modes de production (fabrication et mise en œuvre), de nouveaux modes de conception et de nouveaux vocabulaires architecturaux [Nilsson 2008].

Yvo Stotz [Stotz 2009] a plus particulièrement analysé le domaine de la géométrie et le processus itératif qui accompagne la conception architecturale. Shaghahegh Shadkhou [Shadkhou 2010] a travaillé sur le passage d'une forme géométrique libre à une forme constructible. Un des moyens développé est un modèle paramétrique générique permettant d'extraire d'une géométrie quelconque une grille d'arc structurelle.

Thierry Ciblac [Ciblac 2010] a étudié des possibilités d'approcher une volumétrie non-standard par des éléments standards, cela passe par la résolution algorithmique de contraintes. Griffith, Sass & Michaud [Griffith, Sass, Michaud, 2006] se sont focalisés sur les liaisons des composants préfabriqués pour interroger la relation entre la modélisation des formes, la structure et les assemblages.

Au delà des aspects recherche, Fabien Scheurer [Scheurer 2005] et l'équipe de « design to production » ont questionné à partir de différentes réalisations (Camera Obscura, Trondheim

2006, Hungerburg Funicular Stations, Innsbruck 2007, Centre Pompidou, Metz 2008) la matérialisation des modèles digitaux en gérant une description paramétrique de composants qui permet le passage d'un modèle sans échelle à la réalisation d'un modèle à échelle 1.

Tous ces travaux et bien d'autres encore visent à matérialiser la production de formes libres par une conception intégrée de composants finaux non standards. Mais peu s'intéressent aujourd'hui à la démarche « inverse » consistant à travailler avec des éléments sources non-standards. A notre connaissance, Christian Stanton [Stanton 2010] est un des rares à aborder la conception architecturale au moyen d'un algorithme mettant en œuvre des éléments spécifiques de ressource irréguliers disponibles. Il ouvre la voie à une démarche attentive aux composants « déjà là » qui est celle dans laquelle nous nous situons.

2 Modélisation caractérisée de la ressource

21 Les éléments de ressource à modéliser

Les différents éléments de la ressource présentent des caractéristiques différentiées qui doivent être identifiées et modélisées afin d'être prise en compte dans le processus d'élaboration de la structure. Cette partie traite de la gestion de la ressource et de son appropriation numérique par le concepteur.

Tout d'abord, les éléments potentiels qui composeront la ressource sont identifiés comme issus d'un des types suivants : bois de démontage, bois non usinés (branchages, troncs avec ou sans ramifications), bois résiduels de l'activité de scierie. Le modèle paramétrique proposé rassemble les propriétés géométriques d'un élément de ressource et peut être adapté en acceptant quelques approximations à tout élément de la ressource, quelque soit son type. Le travail de modélisation de la géométrie d'un élément de ressource porte principalement sur les branchages dont la forme est aléatoire. Le modèle complexe pourra par la suite être adapté sans difficulté à des éléments rectilignes simples.

Cette démarche permet de valoriser une ressource locale qui peut être présente sur un site [Stanton 2010] tout en explorant un grand nombre de possibilités formelles pour sa mise en œuvre au moyen de l'outil algorithmique.

22 Le modèle paramétrique

La portion élémentaire est l'entité de base qui va être reproduite et positionnée dans l'espace pour constituer le modèle dans sa globalité. Une portion élémentaire est définie par deux points disjoints, une flèche et une section d'extrusion. Les deux points définissent les extrémités de la portion élémentaire. La flèche donne la distance entre le centre du segment reliant les extrémités et un troisième point se trouvant dans le plan médian du segment. L'arc de cercle passant par les deux extrémités et ce troisième point constitue la fibre médiane de la portion élémentaire le long de laquelle est extrudée la section de l'élément. On comprend à travers cette définition que le modèle global de l'élément de ressource se décomposera en portions de cercle ou de droite de section constante. On fait ici l'approximation suivante : il est possible de discrétiser une courbe gauche quelconque en des portions d'arc de cercle. Une fois cette portion élémentaire définie, on lui crée une ramification pour obtenir l'entité suivante.

Le tronçon élémentaire est produit à partir de deux portions élémentaires positionnées l'une par rapport à l'autre afin de créer une ramification. La première portion élémentaire est positionnée selon la fibre médiane principale de l'élément de ressource, on la nomme portion élémentaire principale. La seconde portion élémentaire est disposée par rapport à la première avec une de ses extrémités sur un point de la fibre médiane de la première, on la nomme portion élémentaire ramifiée. Cette ensemble en « y » constitué de deux portions élémentaires est paramétré angulairement et linéairement par rapport à la fibre médiane de la portion élémentaire principale. Les deux portions élémentaires sont paramétrées indépendamment l'une de l'autre en termes de longueur, courbure et section. L'étape suivante consiste à juxtaposer des tronçons élémentaires pour obtenir le modèle de l'élément de ressource.

Le *modèle* de l'élément de ressource est limité dans notre étude à la juxtaposition de cinq tronçons élémentaires. Les cinq tronçons éventuels sont disposés bout à bout de façon à obtenir cinq fibres médianes ramifiées réparties le long d'une fibre médiane principale. Selon l'élément de ressource à modéliser, le modèle peut comporter moins de cinq tronçons et certains tronçons peuvent être dépourvus de ramification. Le modèle de base constitué d'une fibre médiane de cinq portions élémentaires et de cinq ramifications est modifié dans sa composition pour correspondre à l'élément de ressource à modéliser.

Le positionnement relatif des portions élémentaires qui vont constituer la fibre médiane principale est paramétré de proche en proche. La figure suivante illustre le propos. Le positionnement se fait par rapport aux segments entre les extrémités de la portion élémentaire principale du tronçon, le segment i est relatif au tronçon i. Un premier angle β, selon l'axe de la normale au plan p généré par les segments i et $i+1$, définit la position du segment $i+1$ par rapport au segment i dans le plan p. Un second angle α selon l'axe du segment i définit la position du plan p par rapport au plan $p-1$ généré par les segments $i-1$ et i. Viennent ensuite les angles : θ pour le positionnement du plan de courbure de la portion élémentaire principale, α_r et β_r pour le positionnement de la portion élémentaire ramifiée et θ_r pour le pour le positionnement du plan de courbure de la portion élémentaire ramifiée.

On obtient finalement un modèle applicable à une grande diversité d'éléments de ressource. Il renseigne l'algorithme qui va être présenté par la suite sur la forme de l'élément de ressource et sur la répartition de la matière le long de cet élément. On se limite ici à des ressources linéiques, la longueur est grande devant les autres dimensions de la ressource. Le modèle obtenu se divise au final en deux parties : une partie linéique qui comprend les fibres médianes (principales et ramifiées) et une partie volumique qui comprends les sections extrudées. La partie volumique renseigne sur la géométrie de la section et peut être couplée à un coefficient dépendant des caractéristiques mécaniques du bois utilisé pour évaluer les performances structurales. Il

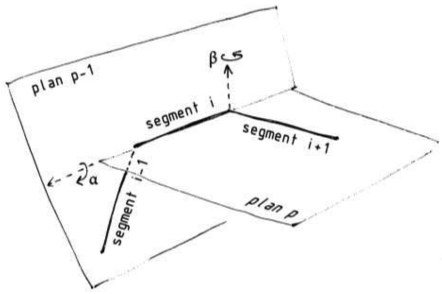

Figure 1 : schémas de paramétrage

s'agit maintenant de prélever les paramètres d'implémentation du modèle sur les éléments de ressource.

23 Le traitement du stock d'éléments de ressource

Maintenant que le modèle virtuel a été présenté, revenons aux éléments matériels de la ressource. La démarche de traitement du stock de ressource consiste à placer sur les éléments les points caractéristiques (extrémités de chaque portion élémentaire définie et point de flèche) puis relever pour chaque élément les paramètres linéaires et angulaires à partir de ces points. La métrologie dans l'espace reste complexe sans l'emploi d'un outil numérique mais le relevé de ces points caractéristiques peut être réalisé à partir d'un scanner numérique. Le nuage de points relevé nécessite toutefois un traitement algorithmique pour en extraire les paramètres, cette question n'est pas abordée dans ce projet.

Dans un second temps, on implémente les paramètres relevés dans l'algorithme pour obtenir le modèle numérique 3D de l'élément de ressource. Les différentes parties qui composent le modèle, fibre médiane principale, fibres médianes ramifiées, extrusions de sections, constituent un seul et même objet qui est transmis à l'algorithme générateur de structure. L'algorithme est ensuite capable d'identifier indépendamment les parties du modèle dont il a besoin pour réaliser les différentes opérations qui sont présentées dans la partie suivante.

3 La mise en œuvre de la ressource

31 Définition du problème

La mise en œuvre de la ressource pose la question de l'intention du concepteur. Cette intention architecturale sera traduite par une nappe de référence, des paramètres de densité de répartition de la ressource et éventuellement des points caractéristiques. L'idée fonctionnelle, formelle ou mécanique qui est visée par le concepteur peut être approchée en définissant correctement les trois données d'entrée précédentes. Nous nous limitons dans cette étude à approcher une surface de référence mais il serait possible de raisonner en termes de ligne ou volume de référence. Des lignes de référence dessinées sur une surface à approcher pourraient par exemple indiquer des « chemins » structurels à privilégier pour la circulation de l'énergie mécanique. On induirait ainsi des orientations préférentielles lors du placement des ressources, ce qui reviendrait à localiser des « armatures » sur la surface. Des notions de gabarit ou d'espace exploitable peuvent également être prises en compte dans la définition de la volonté architecturale du concepteur.

L'enjeu du travail de recherche a été d'identifier et d'isoler des étapes élémentaires de réflexion constructive pour parvenir à les écrire sous la forme d'un algorithme. Le raisonnement mené par un concepteur pour élaborer une structure à partir d'éléments irréguliers en bois peut être décomposé en une succession d'opérations élémentaires qui se répètent. Il vient rapidement à l'esprit la « cabane » de branches confectionnée à partir d'éléments tous différents et surtout disponibles sur place, imposés et non imaginés. Les travaux relatés dans cet article visent à traduire sous la forme d'un algorithme la réflexion menée par l'individu qui érige sa cabane en y incorporant des notions de stabilité et de résistance mécanique.

Le positionnement d'un élément de ressource sur la surface de référence constitue la première étape du raisonnement. L'algorithme procède à une répartition de ce même élément de ressource dans différentes positions possibles en différents points sur la surface de référence. La surface se trouve ainsi couverte d'une multitude de positions possibles pour un élément appelée *population de positions possibles*. La deuxième étape du raisonnement consiste à sélectionner parmi cette population la position optimale selon des critères de positionnement qui seront détaillés par la suite. Une fois la position optimale retenue, le processus est répété pour un nouvel élément de ressource tout en prenant en compte l'élément qui vient d'être disposé. Le processus est réitéré ainsi de suite jusqu'à saturation de la surface de référence. La saturation de la surface correspond au critère de densité de répartition présenté par la suite.

32 Développement d'une entité élémentaire de l'algorithme

321 Production de la population de position

La production de la population de positions est réalisée de deux façons différentes selon le type de placement que l'on souhaite imposer à la ressource : placement avec *un* ou *deux points* contraints. Ces points contrains dans le positionnement de l'élément sont appelés *points de destination*.

Dans le cas d'un point de destination unique, le processus de génération de la population de position se décompose en deux temps :

- Premièrement, constituer des *bouquets* de positions possibles. L'élément de ressource à positionner se voit attribué sur sa fibre médiane un certain nombre (déterminé par le concepteur à travers un paramètre de densité de découpage) de points fixes de rotation. L'élément est ensuite

mis en rotation selon les trois directions de l'espace autour de ces points fixes. La quantité de positions angulaires possibles autour de chaque point fixe est déterminée par le concepteur. On comprend que plus cette quantité sera élevée, plus la population de positions possibles sera conséquente, ce qui optimise le placement mais augmente le flux d'information à traiter par l'algorithme. On obtient ainsi autant de *bouquets* de positions possibles que de points fixes de rotation.
- Deuxièmement, répartir les *bouquets* de positions possibles sur des points de destination en lien avec la structure en cours d'élaboration. Ces points de destination peuvent être de deux natures : soit des points de la surface de référence, soit des points d'ancrages sur des éléments de ressource déjà positionnés sur la surface. L'algorithme dispose chacun des *bouquets* sur chaque point de destination, l'ensemble de ces positions constitue la population de positions possibles.

Dans le cas d'un couple de points de destination, la génération de la population se décompose également en deux étapes :
- Premièrement, identifier des couples de points de destination susceptibles de générer des axes de rotation pour l'élément à positionner. L'algorithme évalue la distance maximale qui peut exister entre deux points de l'élément à positionner. Ensuite, ne sont retenus que les couples de points de destination éloignés d'une distance inférieure à cette distance maximale. Des axes de rotation sont générés à partir de chaque couple de points retenu.
- Deuxièmement, générer des *fagots* de positions possibles autour des axes de rotation disponibles. Sur l'élément à positionner sont créés des couples de points dont la distance entre les deux est égale à celle entre les points de définition de l'axe de rotation. L'élément est ensuite placé sur la structure de façon à faire correspondre les couples respectifs de points, puis l'élément est mis en rotation autour de l'axe pour générer le *fagot* de positions. L'ensemble des *fagots* de positions possibles obtenu constitue la population de positions possibles.

322 Tests de sélection de la position optimale

Une fois la population de positions possibles constituée, il s'agit de retenir la position optimale selon les critères définis par le concepteur. Nous ne retenons ici qu'une position pour simplifier la démarche mais ce choix est subjectif car la deuxième ressource selon le classement par critères peut être toute aussi intéressante pour le développement de la structure. Une démarche plus fine consisterait à retenir un certain pourcentage de meilleures positions et de poursuivre l'élaboration de la structure pour chaque possibilité. Le résultat obtenu serait une population de structures répondant toutes aux critères mais proposant des agencements différents. Ce point pourra faire l'objet d'approfondissements ultérieurs.

La population de positions possible est soumise successivement à trois tests : le test d'appartenance à la surface de référence, le test de densité de répartition et le test de proximité avec la surface de référence.

- Le *test d'appartenance à la surface de référence* vérifie que tout point de l'élément positionné peut être projeté normalement sur la surface de référence. Ce test binaire élimine toutes les positions pour lesquelles une partie de l'élément est hors du champ d'appartenance de la surface de référence. La population des positions qui remplissent ce critère est transmise au test suivant.
- Le *test de densité de répartition* permet à la fois de veiller à la répartition uniforme de la ressource sur la surface de référence et d'éviter les situations de chevauchement trop important de différents éléments de ressource dans l'élaboration de la structure. Ce test est conçu de la façon suivante : dans un premier temps, un maillage de points est réparti uniformément sur la surface de référence, dans un deuxième temps, chaque élément positionné capte dans un rayon d'influence une partie des points qui sont alors supprimés du maillage. (Le rayon d'influence dans lequel les points sont captés est défini à partir des caractéristiques mécaniques du bois employé et des performances visées pour la structure.) Ainsi, à chaque élément positionné, la quantité de points disponibles sur le maillage diminue. Pour chaque position possible d'un élément, l'algorithme calcul le nombre de points capté. Le concepteur décide de ne retenir qu'un certain pourcentage des positions captant le plus de points. Cette population est ensuite soumise au troisième test. Lorsque dans toutes les positions possibles, aucun point ne peut être capté, c'est que la surface de référence est saturée et alors l'algorithme s'arrête.
- Le *test de proximité avec la surface de référence* vise à retenir la position qui épouse au mieux la surface de référence. Pour cela, des points de l'élément positionné sont projetés sur la surface de référence et l'algorithme somme les distances entre chaque point et son projeté. La position dans laquelle cette somme est la plus faible est retenue comme la position optimale.

Les opérations de positionnement et les tests de sélection qui viennent d'être présentés constituent des entités algorithmiques à dupliquer et connecter les unes aux autres pour obtenir l'algorithme générateur de la structure.

33 Composition du processus de génération de structure

Le premier facteur déterminant le processus de génération de la structure est la surface de référence elle-même. Une fois la surface-enveloppe de l'objet architectural définie, on peut procéder de deux façons :
- soit utiliser telle quelle cette surface de référence pour y répartir de manière uniforme la ressource sans imposer de direction à la structure. La structure résultante est un entrelacement d'éléments de ressource à l'image d'un nid d'oiseau (cf. figure 4).
- soit définir à partir de cette surface une grille d'arc unidirectionnelle dont les arcs constituent les surfaces de référence à approcher. On utilise un algorithme capable d'extraire d'une forme non standard une grille d'arcs structurelle [Shadkhou 2010]. La répartition des éléments de la ressource est dans ce cas orientée et rassemblée au niveau d'arcs structurants.

Une fois la surface de référence définie, le second facteur déterminant le processus de génération de la structure est l'organisation des étapes élémentaires au sein de l'algorithme. Une opération de positionnement est associée à la combinaison des trois tests de sélection pour ne retenir en sortie qu’une seule position. Les différentes entités ainsi constituées sont juxtaposées pour former l’algorithme. L’algorithme procède ensuite à un traitement linéaire de la liste des modèles 3D des éléments de la ressource. Le concepteur de la structure doit penser en conséquence l’ordonnancement de cette liste. Il peut être réalisé selon différents critères de l’élément de ressource : encombrement, section, masse… en fonction des intentions.

Une première méthode consiste à placer les éléments sur la surface de référence en cherchant à chaque fois un ou deux points d’ancrage sur les éléments déjà positionnés. On obtient de cette façon une structure dans laquelle chaque élément est en contact avec au moins un autre élément (cf. figure 4), il s’agit alors de penser l’articulation entre chaque éléments afin de rigidifier la structure. La question des nœuds entre les éléments n’a pas été approfondie, mais deux pistes pouvant être combinées ont été envisagées. Il serait possible de traverser les éléments au moyen d’une tige fileté (inconvénient : cela crée un risque d’éclatement de l’élément de ressource dans le cas où il serait soumis à des efforts de rotation) ou utiliser des colliers orientables d’échafaudages [Douthe 2006] (inconvénient : cela impose un domaine restreint de sections pour les éléments de ressources).

Figure 2 : bois solidarisés au moyen de tiges filetées - détail d'une réalisation de Polissky

Figure 3 : collier orientable utilisé pour le montage d'échafaudages

Une seconde méthode consiste à différencier plusieurs phases successives. Lors de la première phase, les éléments les plus encombrants sont positionnés de manière libre sur la surface de référence. Il n’y a pas de contrainte de contact entre eux afin d’optimiser leur positionnement. Dans la seconde phase, les autres éléments sont positionnés avec deux points d’ancrage sur les ressources de la première phase. La structure obtenue possède un premier réseau d’éléments de grande taille indépendants les uns des autres sur lequel vient s’ancrer un second réseau d’éléments de plus petite taille pour solidariser l’ensemble.

Il faut également envisager la possibilité de repérer parmi les éléments positionnés ceux dont les positions interfèrent afin de créer des connexions en ces points de rencontre. Ces connexions supplémentaires participeront à la rigidité de la structure. Il est important de noter qu’à cet avancement du projet, les nœuds entre les éléments modélisés sont localisés à la rencontre des fibres médianes et que l’excentricité amenée par la section de chaque élément (et éventuellement par le système de liaison) n’est pas prise en compte.

Les possibilités d'organisation de l'outil numérique de conception architecturale présentées ici ne sont pas exhaustives. L'intérêt du fonctionnement par entités algorithmiques élémentaires réside dans cette liberté de composition dont dispose le concepteur pour mettre en œuvre la ressource.

La figure suivante présente le positionnement effectué par l'algorithme d'éléments de ressource (en vert) sur une surface de référence (en rouge) qui a la forme d'un demi-cylindre.

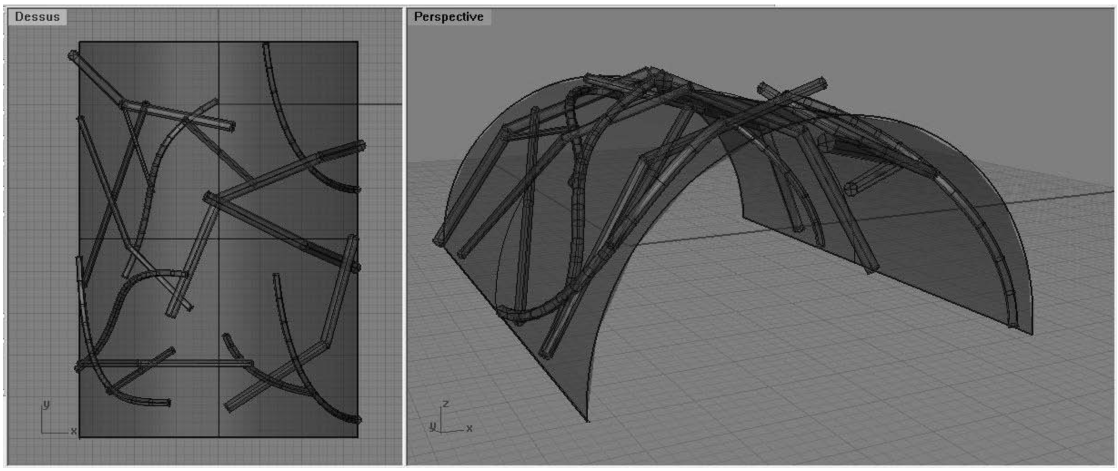

Figure 4 : Visualisation dans l'interface Rhinoceros d'éléments de ressource positionnés sur une surface

5 Conclusion

Le travail de recherche prospective qui a été mené nous permet de conclure sur la pertinence d'aborder la conception architecturale avec comme point de départ le matériau et ses caractéristiques géométrique et mécanique. Le recours à l'outil numérique pour la gestion de modèles complexes permet dans le même temps au concepteur de disposer d'une représentation visuelle explicite dans le modeleur 3D Rhinoceros. L'approche proposée permet d'intégrer dans la structure des éléments dont les formes et les dimensions diffèrent tout en optimisant leur positionnement. La complexité de conception induite par l'introduction d'une ressource irrégulière se trouve résolue par un algorithme qui met en œuvre les composants modélisés et permet ainsi d'explorer les différentes configurations possibles répondant aux intentions architecturales du concepteur.

L'idée développée ici consiste à prendre en considération la matière et la structure dès les prémices de la conception formelle. La démarche vise à générer à partir d'éléments existants la capacité constructive la plus grande, à concevoir en limitant au maximum les opérations industrielles de transformation en vue de réduire l'empreinte énergétique de la structure.

Un développement possible consiste à affiner le positionnement des éléments de ressource au moyen d'un critère plus précis de l'ordre du maillage. Il ne s'agirait plus uniquement de répondre à une densité mais d'assurer un certain pourcentage des liaisons du maillage. Ce maillage pourrait être envisagé dans la surface de référence comme dans un volume de référence. Cette méthode imposerait des orientations pour le positionnement des éléments et garantirait la rigidité de la structure.

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COLLABORATIVE CONSTRUCTION PLANNING: TOWARDS 4D VISUALIZATIONS ADAPTED TO PRACTITIONERS REQUIREMENTS

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ABSTRACT

Managing the intervention of various actors during the construction phase is a recurrent issue in the construction sector. This is partly due to the multiplicity of stakeholders and the need to manage interfaces necessary for efficient planning and coordination of construction tasks. 4D CAD technology appears to be an innovative approach to answer such issues. It consists in combining a 3D model with the time dimension, in order to simulate the progress of works construction along the time.

Our main hypothesis is that the use of 4D to support the actors' collaborative work is not adapted enough to the need of the sector because the classical view (Gantt + 3D model) does not take into account the specific requirements related to particular usages (planning of interventions and reservations request for a contractor; simulation and integration of works' interfaces for an engineer, etc..). It is therefore challenging to adapt the visualization to business needs of users.

Developments in Human-Machine Interface and Information Visualization fields could allow us selecting user views properties (I.e. Structure, Quantity of information displayable, Graphical attributes, Content description, Interaction principles, Business view) and compose "business views". Therefore, the article propose taxonomy to describe user views in order to setup a method for business visualization design, enabling to: 1) Identify business tasks (usages) related to the roles of different users, 2) Offer services tailored to different usages, and 3) Suggest visualization modes fitting each usage on the basis of our visualization model.

In a case study we formalize a collaborative process to identify the usages of each practitioners involved in the collaboration construction process planning. It especially targets collaborative management of works' interfaces. Then, after defining the required services, we suggest combining visualization methods suitable for each use in order to achieve views composition for each stakeholder.

Keywords: Construction process, Collaboration, 4D CAD, Human-Computer Interface, Information visualization, Business view, Model driven engineering

1. INTRODUCTION

Managing the intervention of stakeholders in collaborative works such as in construction sector is an important issue. The main reasons are the multiplicity of stakeholders coming from different trades and also the need of managing work's interfaces between them. This issue has been previously explored (Hanrot 2003, Tahon 1997) but the question remains recurring. It is therefore necessary to explore new solutions both on human side of collaboration (i.e. processes and working practices) and on the technological side. Thus, 4D CAD appears to be an innovative approach to support the simulation of the construction activity. Several uses of the 4D CAD have been proposed and tested since its emergence (Chau & *al.* 2005). From the simple simulation of the construction to interventions and reservations management, the proposed developments provide solutions more or less relevant to the problem.

An important aspect of the construction industry is the flexibility that characterizes projects' management. Indeed, each stakeholder of a cooperative project's context has his own interests, his methods and specific tasks. In this context generic solutions are difficult to adopt successfully. It is then important to adapt solutions to the needs of users. One of the key points in adapting CSCW tools (groupware) is to design visualizations matching the business requirements of users. Considering previous 4D developments, the standard view (i.e. Gantt planning associated with 3D model) currently proposed to different actors in 4D CAD tools does not take into account this adaptation. Specific requirements related to tasks performed by particular roles (planning of interventions and reservations request for a contractor; simulation and integration of works' interfaces for an engineer, etc…) are not considered.

This work relies on previous works (Kubicki & Halin 2010) that mainly aim to model the collaborative context of construction projects and to propose IT services and business views based on business tasks requirements. In this paper we will first make a brief state of the art of 4D CAD developments in the construction field in order to identify activities and services used to support the collaborative work. Then, an overview of research works in the fields of Human-Computer Interface and Information Visualization will allow us to define taxonomic attributes, in order to propose a metamodel that can describe "business views". As an application, we suggest a scenario of collaborative use of 4D model helping us to identify the tasks of different stakeholders, to define services and possible user views for these tasks. The developed metamodel allows us to describe and compare the user views in order to choose the most adapted one for each task and to compose coordinated multiple views for each actor involved in the process.

2. 4D USE IN AEC AND IMPORTANCE OF ADAPTED VISUALIZATION

4D CAD technology consists in linking a three-dimensional (3D) model of a construction project with the works' planning. It leads to obtain an "augmented planning" that can represent the construction progress over time (Kubicki 2006, Chau & *al.* 2005). The use of 4D helps to resolve recurrent problems in the AEC projects. To this end, several applications have been proposed and tested. (Sriprasert & Dawood 2003) made the assumption that in complex and simultaneous construction projects, reliable planning is central to effective collaboration. But they observed that the thousands of articles published during the previous 50 years on construction planning are very fragmentary and have not yet provided a universal system that addresses a typical problem in the construction sector. They proposed a method called "Planning multi-constraint" and developed a 4D prototype embedded in the environment of Autodesk Architectural Desktop. (Chau & *al.* 2004) estimated that the visual link between the timing and conditions of construction site could facilitate decision-making during both phases of planning and construction. The focus of 4D CAD developments has often been placed at the building components, always missing useful features that can help manage the site in the following areas: generation of on-site usage patterns, estimation of quantities of building materials help and costs estimate. To repair these deficiencies, they designed a 4D visualization model for both construction managers to plan daily activities more effectively, and also add to knowledge and understanding the relevance of modern computer graphics to the responsibilities of manager of the construction site. (Kubicki 2006) has particularly mentioned the use of 4D as an attractive solution since, by integrating 3D model and Gantt chart, it can assist the preparation phase of construction by the 3D analysis sequence of implementation, and shows the during construction. Going further, he imagined to generalize the 4D visualization (planning + 3D model) by linking it to a third "view" specific to the coordination, i.e. the construction meeting report. There would thus be the trio: meeting reporting, 3D model and schedule to navigate through coordination information and improve understanding of the state of activity by each actor. To show the feasibility, he proposed a prototype (Bat'iViews). (Lu & *al.* 2007) proposed a construction planning method that integrates operations simulation with critical path method (CPM)-based 4D-CAD in order to provide a more useful tool that overcomes the shortcomings of the current ones, and presented a trial application of the method on a precast viaduct construction project in Hong Kong. (Seok & *al*. 2009) established that "the link methodologies in current 4D CAD viewer should be improved with understanding of characteristic by each project type and suggested a link method in 4D CAD system for plant project management.

Furthermore, studies have been conducted to assess the real value of the use of 4D CAD models in construction projects. (Staub-French & Khanzode 2007) worked on two different building construction projects in California that have implemented 3D and 4D modeling in varying degrees throughout the design and construction process. They concluded that 3D and 4D modeling may have a significant impact on project implementation, including increased productivity, elimination of interference on the ground, pre-production increased, fewer times, fewer requests for information, unless change orders, unless increased costs and decreased time. They proposed a guideline to help teams to implement 3D and 4D models in construction projects, particularly to address technical problems, procedural and organizational issues that are often barriers to adopting these technologies. (Dawood & Sikka 2007) conducted an experiment among participants of different age groups (11-22 years). The aim of the experiment is to assess how much information participants are able to extract and retain in their minds by the analysis of two different formats of graphical representation (4D model and 2D). The research results have provided quantitative data showing that the 4D group outperformed the 2D group by constructing 7% faster the physical model, spending 22% less time to extract intelligence information from the construction and reconstructing 77% less compared to the 2D Group. The 4D group participants were able to communicate and coordinate better compared to participants in the group 2D. (Mahalingam & *al*. 2010) made an assessment, through the study of four construction projects underway in India and the applicability of 4D CAD in construction projects. They established that it could offer advantages at the stage of development and project planning, and in the construction phase. According to them, it seems particularly useful during the construction phase for comparing the constructability of the working methods, to visually identify conflicts or clashes (overlaps), and as a visual tool for contractors, customers, subcontractors and suppliers to discuss and plan the project progress.

As we can see, the 4D models are of obvious interest to the AEC. In addition, efforts have been made to improve the collaborative 4D planning (Sriprasert & Dawood 2003, Zhou & *al*. 2009). But adapting visualization to the business requirements of different actors still remains a challenging issue. It should be noted that some characteristics of AEC have to be taken into account. Indeed, "an AEC operation is characterized on the one hand by the particularities of the architectural object (situated object, prototype object) and on the other the specificities of the cooperative tasks (variable teams, decentralization of decision)" (Kubicki & al 2006). Then actors tend to use different visualization modes, depending on their role. It is therefore necessary to consider adapting the display to business needs of users. "Therefore visualization techniques of project context's information could be designed according to the tasks, and be identified as an adaptable visualization service which could be chosen, integrated and used by the actors to perform their activity inside a project" (Kubicki & Halin 2010). Moreover many works showed the value of adapted visualization (Davidson 1993, Norman 1994). So, visualization must be designed not only in terms of aesthetics and ergonomics, but also as meeting real needs related of each user and the actions they will have to operate within their design and construction process.

3. TOWARD ADAPTED BUSINESS VIEWS IN 4D CAD – SUPPORTED COLLABORATIVE WORK IN AEC

3.1 METHOD

Above we have shown the benefits of the use of 4D CAD as a medium for collaborative planning activity in AEC. In most of the scenarios encountered in the literature, the same 4D view (3D + Gantt) is proposed to all players. Of course, as said, this view does not take into account the specific needs associated with certain tasks. In addition, an important principle of information visualization recommends not displaying more information than necessary to avoid cognitive overload. We propose to match business views to the tasks of actors. In order to design views adapted to actors' tasks in a 4D CAD use context, we followed a multi-step approach as shown in Figure 1. Initially, it's important to work on formalizing a process scenario. This process will allow to clearly identifying the tasks of each actor. Identifying such tasks helped us to understand the related information needed to achieve them and the visualization techniques that could be used (Step 1). After that, the visualization needs could be identified, i.e. the interaction principles and specific visualization tasks related to business tasks we previously identified (Step 2). Then, it would be possible to describe and compare possible visualization techniques in order to choose the most adapted one, according to the visualization needs. That will finally enable to design the most adapted business view (Step 3).

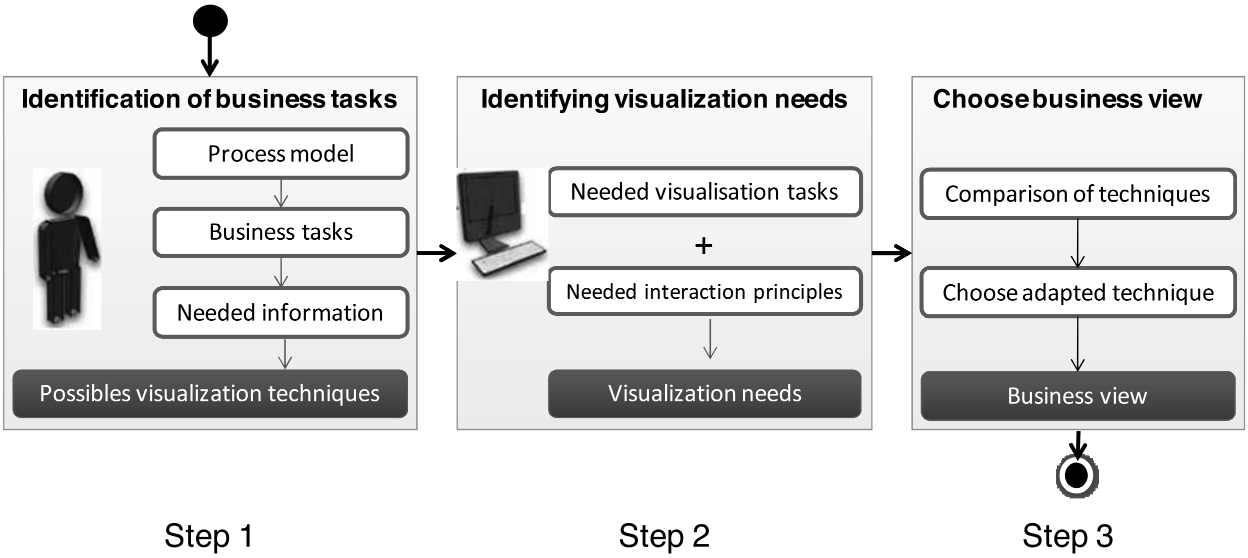


Figure 1: Multi-step approach to compose business view

To compare possible views, we propose to model them. Model Driven Engineering approach recommends the use of metamodels to define domain languages. The approach enables the design of models which have to be conformed to their metamodel. Applied to business views, the first step in the modeling is to define a business view metamodel.

3.2 BUSINESS VIEW METAMODEL

According to our specific context and to the literature, a user view displays content, using a technique. (Lohse & *al*. 1994) presented a classification and properties for visual representations. They identified ten properties for visual representation that are: *spatiality* (spatial or non spatial), *temporality* (temporal or non temporal), *comprehensibility* (easy to understand or hard to understand), *continuity* (continuous or discrete), *concrete or abstract*, *numericity* (numeric or non numeric), *dynamism* (static or dynamic), *attractivity* (attractive or unattractive), *focus* (emphasizes whole or emphasizes parts) and *quantity of information* (conveys a lot of information or conveys a little information). They also proposed eleven categories of representations: *structure diagrams, cartograms, maps, graphic tables, process diagrams, icons, time charts, network charts, pictures, tables, graphs*. (Keim 2002) classified data in 7 display formats: *one-dimensional, two-dimensional, multidimensional, text and hypertext, hierarchies and graphs, algorithms* and *software*. This is close to the work of Shneiderman (1996) who described visualization contents into seven classes (one-dimensional or linear, two-dimensional, three-dimensional, temporal, multidimensional, trees, networks). By their nature (Mazza 2009) classified the data into 3 main categories (*quantitative, ordinal* and *categorical*) and proposed a graphical elements typology.

A business view also involves interaction techniques. These techniques are characterized by their type, their mode and their interactivity level. Following Keim (2002) there are 5 types of interaction: *dynamic projection*, *interactive filtering* (browsing and querying), *interactive zoom*, *interactive deformation* and “*Link&Brush*” (Keim

2002). Tweedie identified five interactivity levels: *manual, mechanized, instructable, steerable* and *automatic* (Tweedie 1997). Spence (2007) considered four interaction modes: *continuous*, *stepped, passive* and *composite*.

These various taxonomies from the HCI and information visualization fields allow us to consolidating business views concepts within the metamodel depicted on Figure 2.

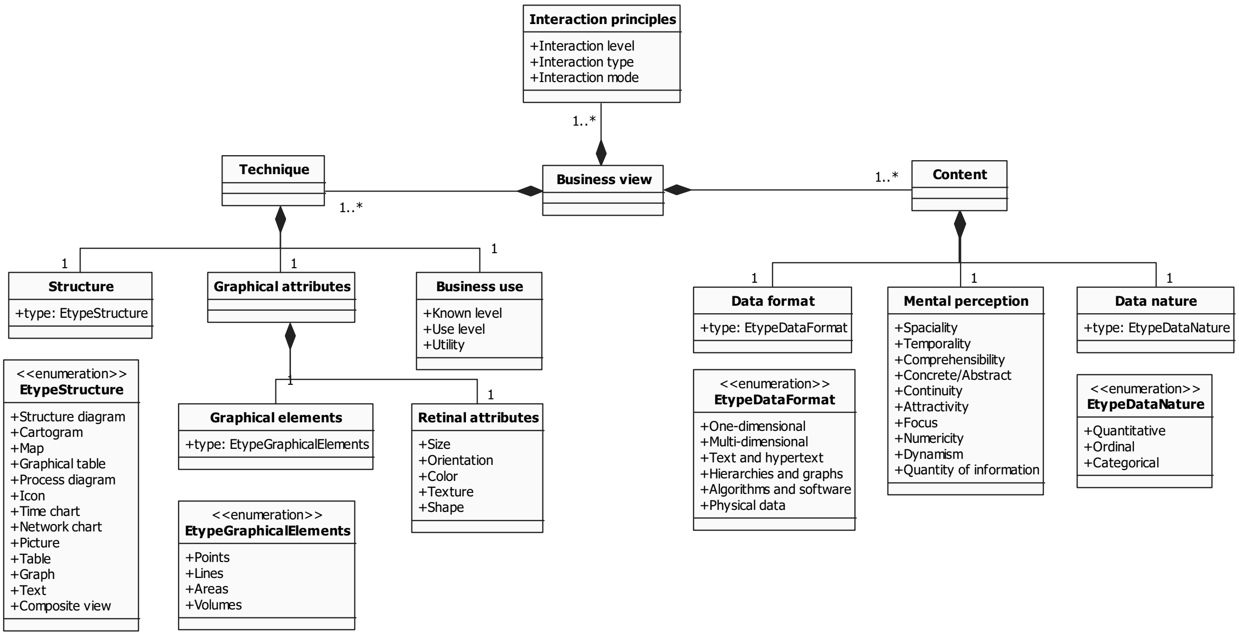


Figure 2: Business view metamodel

4. CASE STUDY

According to the first step of the proposed method, Figure 3 depicts the process model that we formalized from our observation and which is related to the management of the interventions sequencing and reservations of the actors involved in a building project. To understand the concept of reservation, Kubicki (2006) gave the example of a reservation for the passage of plumbing in a slab. The mason makes the reservation in the slab on the request of the plumber who specifies to him the size and location of the ducts.

The scenario shows three kinds of actors involved: supervisor, engineer and contractors. This scenario brings up the tasks of these different actors. Note that this process is simply an example of scenario that shows a possible use of 4D for construction planning, integrating the reservations management. This example is based on our experience and knowledge as well as literature review. Our future works will focus on inventorying and validating all types of tasks in construction planning.

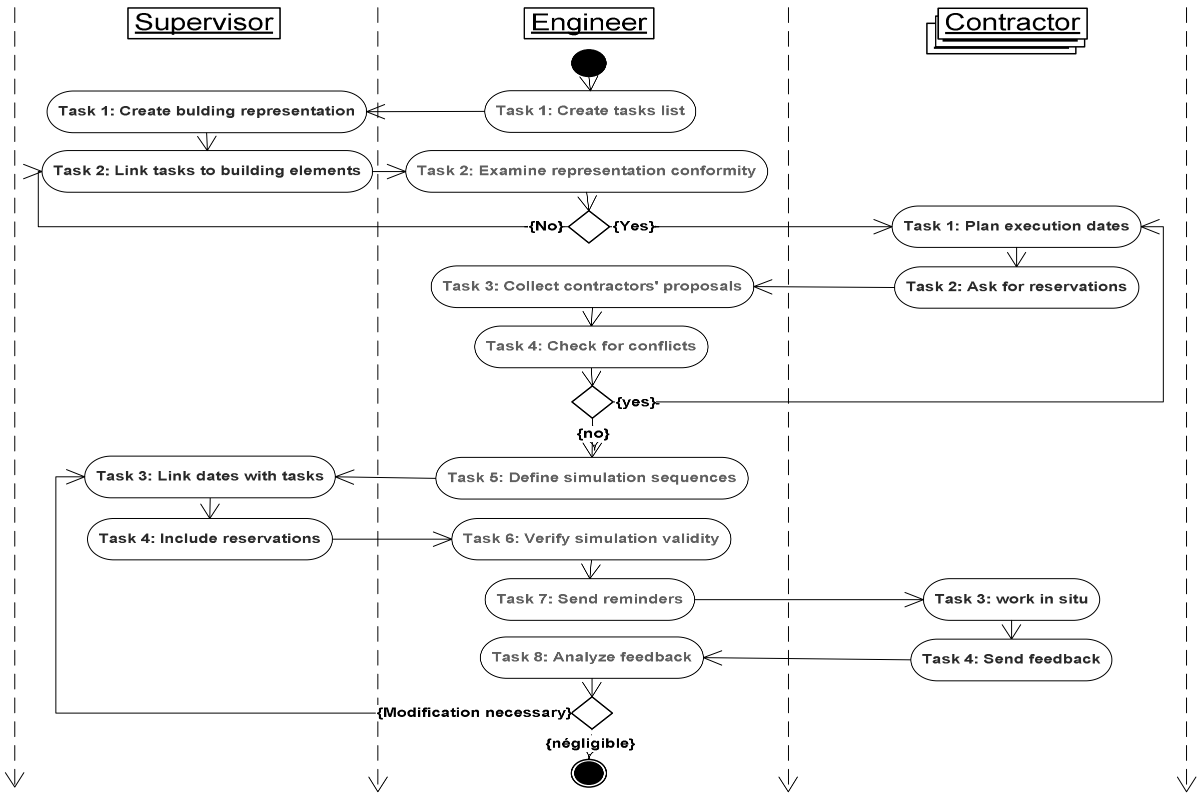


Figure 3: Collaborative process to manage actors' interventions sequencing

In table 1, we summarized actors' tasks, information needed to perform them and possible views. In the table ***{a(b,c), d(e)}*** represents a composition of views ***a*** and ***d***. ***b*** and ***c*** are the two parameters of the view ***a*** and ***e*** is the only one attribute of view ***d***. The building elements are the different elements that compose the building. These elements correspond to some business tasks, according to the actor who is responsible of their realization. The realization of a task begins at a certain date and finishes at another date (execution date). That determines the duration of the task. One important information need is the location of the reservations. In the example of the reservation for the passage of plumbing in a slab, the plumber has to specify to the mason the reservation location according to size and specificity of the ducts that will be used. After working *in situ*, the contractor can send some feedbacks. Feedbacks are some notes about important changes that could impact the following of the building process.

The listed possible views are based on a previous experience (Kubicki & *al*. 2007) that aimed to propose a model driven architecture for multi-view representation of the cooperation context. Of course, these views are not exhaustive and deserve to be supplemented. So, one aspect of our ongoing work is to identify other existing visualization techniques and to describe them from the metamodel presented.

After reading table 1, we see quite clearly that the tasks and the needed information are different from one actor to another according to their viewpoint in collaborative project. At this point, we can notice that according to their tasks, the contractors don't need to edit the 3D building representation. They often require working with lists and/or forms and a 2D representation to work in situ. At the contrary, supervisor (task 1) and Engineer (task 2 and task 6) need to work directly on an editable representation of the building. As possible visualization techniques, 2D plan and 3D view can be chosen to achieve the tasks Figure 4).

Table 1: Tasks and needs of information for each actor

SUPERVISOR		
BUSINESS TASKS	**INFORMATION NEEDS**	**POSSIBLE VIEWS**
Task 1: Create the building représentation	Building elements, Building representation	- *{List view(building_element), 2D plan view},* - *{List view(building_element), 3D model view}*
Task 2: Link tasks to building elements	Tasks, building elements	- *{List view(building_element), List view(tasks)}* - *{Table view(building_element, tasks)}*
Task 3: Link dates with tasks	Execution dates, duration, tasks	- *{Table view(task, duration, date)}* - *{List view(task), Table view(task, date, duration)}* - *{List view(task), Pert view(task, earlier date, late date)}* - *{Gantt view(task, beginind date, end date)}*
Task 4: Include reservations	Tasks, reservations locations	- *{Table view(task, reservation location)}* - *{(Table view(tasks, reservation), reservation sketch}*

ENGINEER		
BUSINESS TASKS	**INFORMATION NEEDS**	**POSSIBLE VIEWS**
Task 1: Create tasks list	Tasks	- *{List view(task)}*
Task 2: Examine the representation conformity	Tasks, building representation	- *{List view(task), 2D plan view(building_element)},* - *{List view(task), 3D model view(building_element)}*
Task 3: Collect contractors' proposals	Dates, tasks, reservations	- *{Table view(task, date, reservation)}* - *{Table view(task, date), Table view(task, reservation)}* - *{List view(reservation), Gantt view(task, beginind_date, end_date)}* - *{List view(reservation), Pert view(task, earlier_date, late_date)}*
Task 4: Check for conflicts	Tasks, durations, reservations	- *{Table view(task, duration, reservation)}* - *{Table view(task, duration), Table view (task, reservation)}*
Task 5: Define simulation sequences	Dates, tasks, reservations	- *{Table view(task, date, reservation)}* - *{Table view(task, date), Table view (task, reservation)}* - *{List view(reservation), Gantt view(task, beginind_date, end_date)}* - *{List view(reservation), Pert view(task, earlier_date, late_date)}*
Task 6: Verify reservation validity	Building representation, reservations	- *{List view(reservation), 2D plan view(building_element)},* - *{List view(reservation), 3D model view(building_element)}*
Task 7: Send reminders	Dates	- *{List view(date)}* - *{Calendar view(date, event)}*
Task 8: Analyze feedbacks	Feedbacks, Dates	- *{Table view(feedback, date)}* - *{List view(feedback), Calendar view(date, event)}* - *{Text view(feedback), Calendar view(date, event)}*

CONTRACTOR		
BUSINESS TASKS	**INFORMATION NEEDS**	**POSSIBLE VIEWS**
Task 1: Plan execution dates	Dates, tasks	- *{Table view(task, date)}* - *{List view(task), Calendar view(date, event)}* - *{Form view(task, date), Calendar view(date, event)}*
Task 2: Ask for reservation(s)	Tasks, reservation request	- *{Table view(task, reservation, location)}* - *{Form view(task, reservation, location)}*
Task 3: Work *in situ*	Reservation locations	- *{Table view(reservation, location), 2D plan view(building_element)}* - *{2D plan(building_element), reservation sketch(position, size)}*
Task 4: Send feedback	Feedback	- *{List view(feedback)}* - *{Form view(feedback)}*

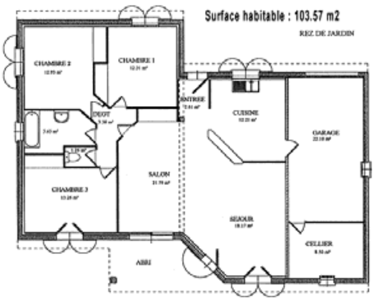
Using the taxonomy of visualization tasks proposed by (Valiati & *al*. 2006), we can, in instance, describe the visualization needs for the engineer's task 6. So, in terms of visualization for this task, engineer will have to:

- *Visualize* the *data* (i.e. building representation)
- *Locate* the *position* (i.e. of reservations)
- *Identify* the *dependencies* (i.e. of tasks and reservations)
- *Compare* the *values* (i.e. of simulation sequences with dates list)
- *Determine* any *variance* (i.e. between simulation sequences and dates list)
- *Infer trends* (i.e. validity or no)

We see that this business task requires some specific visualization tasks and a visualization technique that enables adapted interaction principles supporting them. In order to do it, we suggest modeling the two proposed techniques (2D plan and 3D views) in order to compare them.

Visualizing the building representation corresponds to a passive mode of interaction and don't call at a particular interaction style. Both 2D plan view and 3D model view can enable to achieve it. To *locate the position of reservations*, engineer need to clearly see them among other kinds of information in the space. Thus, he needs a visualization technique that **emphasis parts**. To identify the dependencies of tasks and reservations, the engineer needs particular interactions that could be **navigation** or **direct manipulations**. Those kinds of interaction are possible with the 3D model view but not with the 2D plan view. Instances to describe the two proposed views are shown in table 2. Differences in attributes values are presented with red color. We can see that the 2D plan view is less adapted for those identified views tasks. For that reason, it is probably better in this case to choose the 3D view that appears more adapted.

In a view design process, our hypothesis is that one can apply the same operation to the other tasks in order to identify the best visualization techniques and propose adapted business views composition for each actor.



2D view

3D view

Figure 4: Two possible views to support engineer task 6

Table 2: instances for modeling and comparison of 3D view and 2D plan view

Attributs			3D view	2D plan view
CONTENT	**Data format**		Physical data	Physical data
	Mental model			
		Spatiality	Spatial	Spatial
		Temporality	No Temporal	No temporal
		Comprehensibility	Easy to understand	Easy to understand
		Concrete - Abstract	Concrete	Concrete
		Continuity	Discrete	Discrete
		Attractivity	Attractive	Unattractive
		Focus	Emphasizes parts	Emphasizes whole
		Numericity	Non numeric	Non numeric
		Dynamism	Static	Static
		Quantity of information	A lot	A little
	Nature of data		Ordinal	ordinal
TECHNIQUE	**Structure of the technique**		Modelling	map
	Business view			
		Kwowledge level	Quite known	Very known
		Use level	Not quite used	Quite used
POSSIBLE INTERACTIONS	**Interaction styles**		Projection dynamique, Déformation, Zoom,…	Zoom
	Interaction mode		Continuous, discret, composite	passive

5. CONCLUSION

The use of 4D CAD in the AEC projects appears as being very helpful in resolving recurring problems in the sector such as the sequencing of the actors' intervention and the reservations' management. However, the existing visualization modes are not always sufficiently adapted to the needs of users.

We proposed in this paper a first version of a "business view" metamodel, incorporating the key concepts found in the literature of HCI and Visualization fields. We suggested a method to adapted business views to the business tasks. In the case study, we showed that it is possible to propose different views to actors according to their tasks. With our metamodel we can model several possible views for a given task and compare them. The interest is to be able to choose the most appropriated according to the visualization needs related to the task.

In the future, we will work to define an experimental protocol, in order to consolidate, improve and validate the construction management process model according to a cooperative context. We will also work on the consolidation of the metamodel. Moreover, we have to describe better our three steps (business tasks, visualization needs and business views). In particular, it is important to deepen the second one (visualization needs) in order to create relationship with the two others. The corresponding model transformations should make our approach operational, and enable to develop a tool that could help to design business views.

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Geometry, design and construction
A parametric model for non standard timber construction

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Abstract. Architectural design is confronted to a renewal of formal vocabulary regarding the advancements on computational techniques. Recent advancements in digital representation and geometric description of architectural form are raising more and more questions in regard to materialization. Construction and assembling constraints are parts of data needed to rationalize a geometric model. This paper reports on part of a research activity aiming at elaborating a tool capable of transforming geometric description of a non-standard form to constructive geometry.

Keywords. Digital fabrication, materialization, parametric modeling, timber construction, digital design tool.

Design – construction

Architectural design is confronted to a renewal of formal vocabulary regarding the advancements of digital design tools. However, the capacity of representing and modeling more and more complex geometries (curves, surfaces …) has been the principal driving objective of the development of many of these design tools. While first generation of such tools were capable of representing and managing basic geometric elements such as points, lines and Euclidean space, recently developed modeling systems offer the possibility of representing and manipulating advanced geometries and higher dimensional spaces (Nurbs, complex curvature …). Although providing the possibility of modeling non-standard complex morphologies design oriented tools tend to restrict the final design to a geometric configuration.

Architectural design's tradition has for long time prioritized the generation of form over its materialization. Materialization and production become important issues only once the design process is worked out. The introduction of CAD-based tools forces architects to work on two and three dimensional geometric representations. This restrictive quality of digital geometric modeling -as explained above- enriches somehow this situation. The family of non standard morphology is transforming to a utopia universe of non constructible virtual object. "If architects don't try to feed material constraints into software, they become moviemakers or image manipulators instead of designers who actually construct things." [alexandro zaero-polo, 2004, 98].

Recent generation of computational assistance to the process of architectural design (associative computer aided design and manufacturing technologies) is based on establishing a flow of information between design and production stages. In such context the issue is to make a link between geometric data and material characteristics of the final design. This is to say how to enrich the geometric model so that it can support the post design phases.

This paper reports on elaborating a parametric model aiming at adding a semantic layer to the geometric model – in the specific field of timber construction. The parametric model is then used to develop a tool capable of generating the structural volume of a non standard surface based on a specific timber construction system. The objective being to provide data needed for production phases, the parametric model is supposed to integrate materiality based on classified timber construction methods.

Digital materialization

Architects often claim they cannot think of a solution, or proceed with the design, when they don't know how and on what it is going to be realized. The decision about how the design's result will be fabricated is thought of usually as the last question. The idea of digitally bridging design and materialization processes in architecture has been explored by several researchers.

Fabian scheurer and his team have questioned through several projects [Camera Obscura Trondheim 2006, Hungerburg Funicular Stations Innsbruck 2007, Centre Pompidou Metz 2008 …] the materialization of a digital model. Based on logic of component as he explains, and the information needed to describe it their experiences challenge the translation of a non scaled digital model to a one to one real object. Shifting the definition of "complexity" -from formal configuration to the context of information processing- the firm works on the basis of parametric description of components to be fabricated. The use of parametric modeling is because of its adaptive capacity to changing context of construction and manufacturing constraints.

Their experiences reveal that construction, assembling process and fabrication methods bring post design processing to the geometric description of the final shape. In translating design data to manufacturing information, one crucial issue concerns construction dimensioning. Detailing and precise two dimensional documents needed to control the CNC machine are not provided by the free form modeled in a CAD environment.

Researches done by Sass, Michaud and Griffith [Griffith, Sass, Michaud, 2006 and 2007] address another issue concerning post-design processing; the problem of assembly modeling. They characterize the process of design to fabrication as following; preparation of a first three dimensional CAD model, elaboration of a construction model (as they name it) containing description of components adapted to local geometry, providing two dimensional arrangements of 3D components to be numerically fabricated and finally the assembling of fabricated pieces.

Focusing on problems posed by assembling of fabricated components, they question the relation between shape modeling, structural and assembling systems. They explore methods of integrating assembly modeling in the CAD model so that design's result be less altered once arriving at assembling phase. Also based on logic of component or sub-object the issue of their researches is based on physical and mechanical behavior of components at their connections.

They have previously developed a plug-in tool – based on a bilateral network of connected ribs– to rationalize complex geometry. As explained above the study is focused on structural efficiencies of bilateral assembly of free form surfaces. This is why parameters related to physical and mechanical characteristics of joining (connections) such as density, friction and thickness affect the behavior of the geometry and are therefore used to generate the bilateral network.
Knowing that a CAD model does not provide post design knowledge, these studies reveal the importance of integrating construction and assembling knowledge as semantic information in the geometric model and the use of parametric modeling in this regard. However, they reveal on the other hand the lack of a generic parametric model - especially in the case of timber construction- to better assist the digital-fabrication link. A model which -by integrating post design information- is capable of supporting different methods of construction.

Parametric model – tool

In this work we try to provide a parametric model with integrated construction and assembling data for timber construction, as the basis of an algorithmic based tool to support production phase.
Our work is characterized by non-standard geometry and its technical vocabulary is focused on timber construction. The principal goal is to generate the structural volume of a given free form. First step was to categorize 5 families of construction methods; Pilling up, tessellation, mesh, membrane and structural frames, as well as assembling; "slotting together", "mortise and tenon" … .This step was followed by elaboration of a parametric model based on morphological, topological and technical characteristics of defined families. The model is then used as the basis for the development of an algorithmic-based tool - a plug-in implemented in Maya. The tool is capable of generating the structural volume and construction dimensioning necessary to provide tool-path.

Morpho – constructional families

As the first step the work started by categorizing 5 families of construction; pilling up, tessellation, mesh, membrane and structural frames [fig. 1] and assembling; "slotting together", "mortise and tenon" …
Construction knowledge refers to topological information and 3D positioning of components while assembling logic defines types of connection and joints between them. This will be the basis for a parametric description of construction and assembling systems providing the possibility of a dynamic interaction between user and the 3D structural volume to be generated.
The piling-up refers to the superposition of horizontal regular or non-regular elements. Following a corbelling system it can support upper superposed elements. The friction between the elements cancels the horizontal forces. A distinction could be made between layered piling-up and modulated piling-up. The tessellation splits up of a structural surface with similar (or no similar) elements, which is usually compatible to the structural frame. Differences between facets would be in terms of shape (triangle, rectangle,

pentagons …) and the folding angle between them. A distinction could be made between facets and waffles.

Figure 1. top-left) piling-up, BWIF Sculptures, Bergen, Norway. top-right) tessellation, Saint Loup chapel, Switzerland. Bottom-left) mesh, Weald & Dowland museum, Chichester England. Bottom-right) framework Observation platform, Trondheim, Norway.

A mesh here is considered as a grid of arcs or network of bars. Interconnected bars are subject to traction and compression. Meshes can form sorts of structural free forms enveloped by a subdivided surface. The (structural) frame is a composition of various structural elements that build a three-dimensional shape. This shape could receive an envelope surface. The membrane is a continuous structural surface made with linear (planks) or surface (panels) elements but assembled with no angle. Vaults or shells represent a variation of the membranes.

Parametric model

As the following step a parametric model was developed based on families explained above. The model provides a parametric description of topological and morphological behavior of predefined techniques of construction and assembling –knowing that the assembling part is not still integrated. To digitally assist the bridge between design and fabrication, the model represents an intermediate phase. It allows for a transformation from a general volume to a detailed representation of components.
The categorization done in the first step showed that the transformation of non-standard geometric model to a 3D construction model can be provided by a grid – an abstract mesh –, a section and finally nodes or intersection points between axes of the grid. The grid is here a sort of operator which integrates part of construction knowledge. The model will then give a parametric definition of the grid and sections (profiles) specified for timber construction methods. Parameterization of nodes will handle assembling.
Two kinds of 2D grid are considered here: regular and irregular one, where the irregular refers to a grid created by random mathematical operations and the regular one can be

either oblique (containing orthogonal) or polar grid. As the first step of the development we focused on a two dimensional regular grid.
An important parameter concerning a grid is the number of superposed sets of axes or better to say number of axes passing from each node. It varies from 1 to 3, where the first case concerns layering and stratification. In any case, each set of axes is defined by its organization; linear, circular, elliptic …, the angle between two sets being the angle between two of their axes and the intervals between axes of each set. There exist constant and non-constant intervals.
The relation between axes of grid and a section (a profile) can be of two kinds: the facets of a subdivided surface encountered by grid axes (edges) or a section extruded along the axes (edges).
A section is defined by its type, its position along the axe and its rotation around it. The type of a section refers to its form; rectangle, circle … as well as its dimensions. In the case of extruded sections they can be either of standard type or customized. The position of each profile is defined by the distance between its gravity center and one end of the axe. In the case of facets the only possible distance from grid will be along Z axe.
Parameterization of the "Napier University", Edimbrough, Ecosse [fig. 2] shows as an example the use of parametric description.

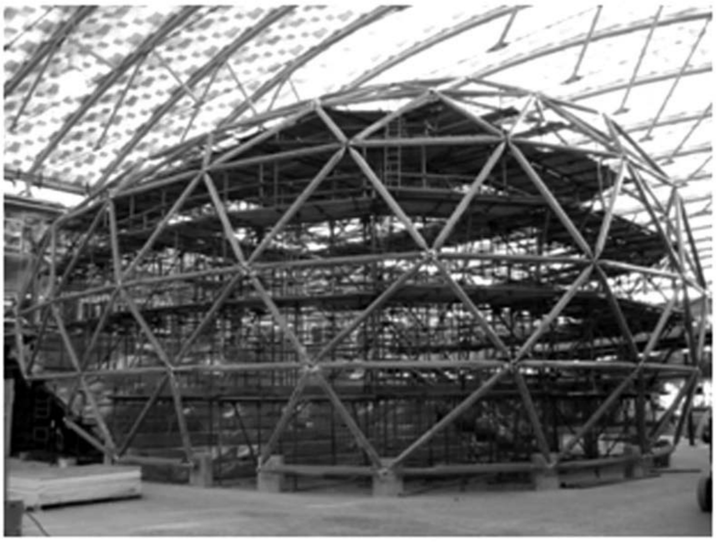

Figure 2. "Napier University", Edimbrough, Ecosse

Here the grid is a regular oblique grid with three axes passing from each point. Organization of all three sets of axes is linear and the angular value is about 60°. Intervals of both two axes are approximately constant. The section is an extruded standard section in the form of circle. Sections at the two ends are identical and there is neither a shift in X nor in Y direction.
The next issue concerns the category of different assembling methods which is not for the moment integrated in the model.

Plug-in development and validation

On the basis of two previous steps a plug-in is being developed which aims at the first time at validating the parametric model;
The process starts by a “grid” creation based on the parametric model. The corresponding 2D grid will be used to transform the initial geometry to the structural volume. Final step is to create assembling geometry in intersection points of rib network- this step is not still developed.
The associative relation between the grid and the structural volume enhances user’s control on the process. Once grid created further manipulations either on its intervals or on angular value will directly affect the three dimensional volume. It is also capable of providing the construction dimensioning (2D documents) ready to pass through a CNC machine. The developed plug-in is implemented in Maya.
To validate the pertinence of the model, it was first used to regenerate the structural volume of an existing project [fig. 3]. At the second time it was used in an educational experience (workshop) with master students of architecture school of Nancy, to create structural volume of a non standard form and to provide necessary construction dimensioning to be fabricated [fig. 4]. It resulted in fabrication of a small prototype with a 3-axis milling machine.

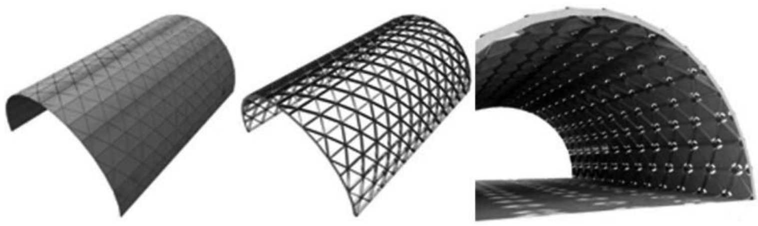

Figure 3. kartontheater Apeldoorn, Hans Ruijssenaars, Netherlands, 1992. Creation of grid, structural volume and the final result using proposed model

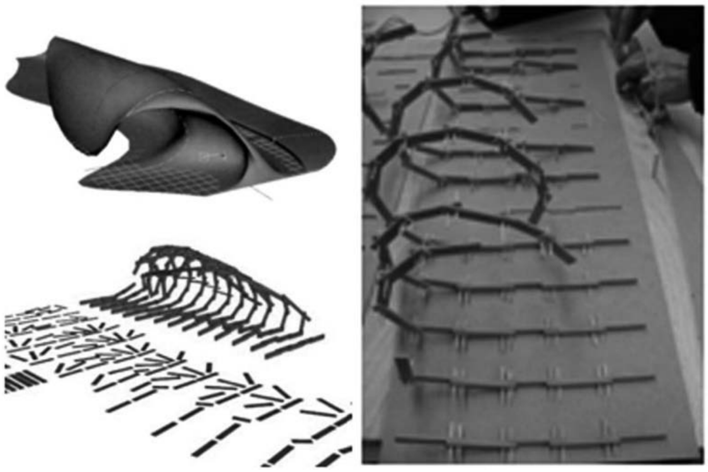

Figure 4. Educational experience; Constructive interpretation, fabrication preparation

Experiences based on one morpho-constructional family don't allow of course for validating the very generic characteristic of the proposed model. It partially validates the principle method and concept at the core of our investigation. Future work consists of integrating other morpho - constructional families.

Conclusions

Materialization of complex curved forms is hardly based on a geometry rationalization based on construction strategies. A solely geometric model is impotent to handle post-design developments. Previous works reveal the lack of a generic parametric model to better assist the design-fabrication link.
In this work we try to provide a parametric model with integrated construction and assembling data for timber construction, as the basis of an algorithmic based tool to support production phase.
A plug-in is being developed, implemented in Maya and validated during a workshop.

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Morphologies numériques

Morphologies numériques

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From nature to manufacture.
International Symposium File To Factory 2009, Crète, Grèce.

Résumé :

De la Nature à la manufacture.
Cet article porte sur un travail réalisé au cours d'un atelier d'une semaine avec des étudiants de l'Ecole d'Architecture de Nancy en France. En s'appuyant sur les progrès des technologies de CAO et de FAO, cet exercice explore le lien entre deux étapes du processus de création d'un objet architectural; la modélisation géométrique d'une part et la préparation de la fabrication d'autre part. L'idée principale est de traiter dans un continuum la création de la forme, de la première idée (image mentale du concepteur), en passant par la description géométrique pour aboutir à une maquette finale.

Shaghayegh Shadkhou, Jean-Claude Bignon 76
Design, fabrication, digital : between digital design and digital fabrication.
ECAADE 2009, Istanbul, Turquie.

Résumé :

Conception Fabrication Digitales : entre la conception numérique et la réalisation numérique.
Ce document présente une pratique éducative visant à analyser le lien entre la conception numérique et la fabrication numérique. CFD (conception, fabrication digitales) est un atelier d'une semaine avec des étudiants en Master recherche (Architecture, Modélisation, Environnement) de l'Ecole d'Architecture de Nancy. Après avoir passé le premier semestre à suivre une formation sur les principes de modélisation, les logiques de calcul et de représentation formelle des données, les élèves sont invités à les appliquer dans un processus de projet. L'exercice est basé sur l'expérimentation de nouvelles approches dans la génération formes qui croisent la géométrie et les aspects liés aux technologies de fabrication et de construction.

Philippe Marin, Hervé Lequay, Jean-Claude Bignon 84
A genetic algorithm for use in creative design processes.
ACADIA 2008, Minneapolis, Etats-Unis.

Résumé :

Utilisation d'un algorithme génétique dans un processus de conception créative.
Cet article traite des mécanismes de croissance naturelle appliqués aux processus de conception architecturale. Nous mettons en œuvre un algorithme génétique dans le cadre d'un outil numérique utilisé dans un processus de conception créative. Ce processus évolutif est évalué au moyen de paramètres environnementaux comme les qualités solaires passives des bâtiments et les exigences du concepteur. Un processus morphogénétique est mis en avant, basée sur une « stratégie de métamorphose ».

From nature to manufacture

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Abstract:

This paper reports on a work carried out during a one-week workshop with students of the architecture school of Nancy in France. Based on the advancements of CAD/CAM technologies, this exercise explores the link between two stages of the process of creation of an architectural object; geometric modelling and respective manufacturing preparations. The main idea is to deal with the continuum of the form creation, from the first idea (designer's mental image), through the geometric description, to the final physical model.

1 Introduction:

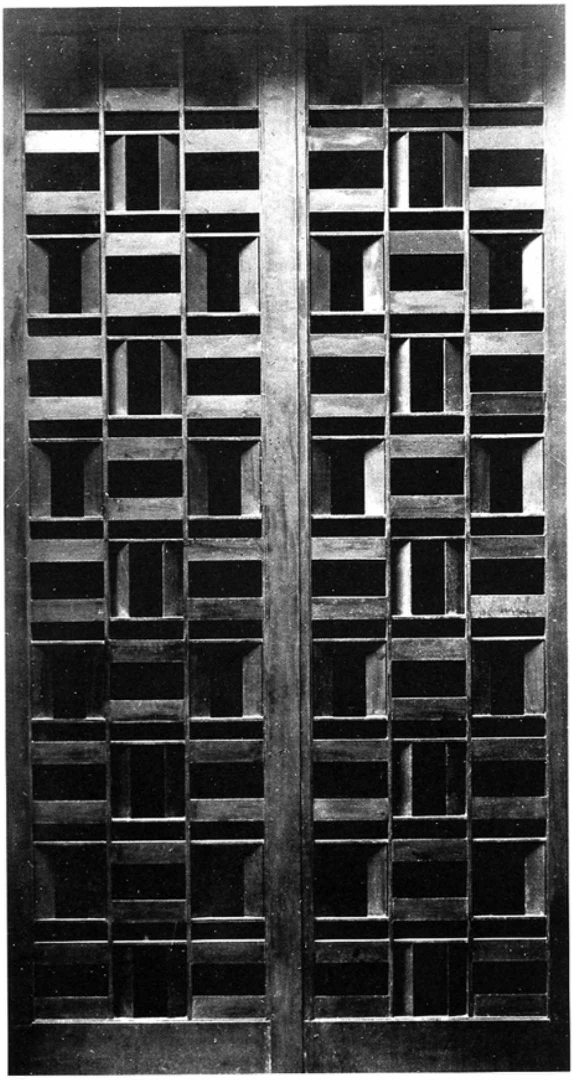
The development of architectural vocabulary is largely related to recent advances in the world of digital design. Advanced CAD tools and geometric modellers allow the creation of forms that overtake Euclidian models. But digital also affects the universe of manufacturing; CNC technologies provide the possibility of creating physical version of design alternatives.

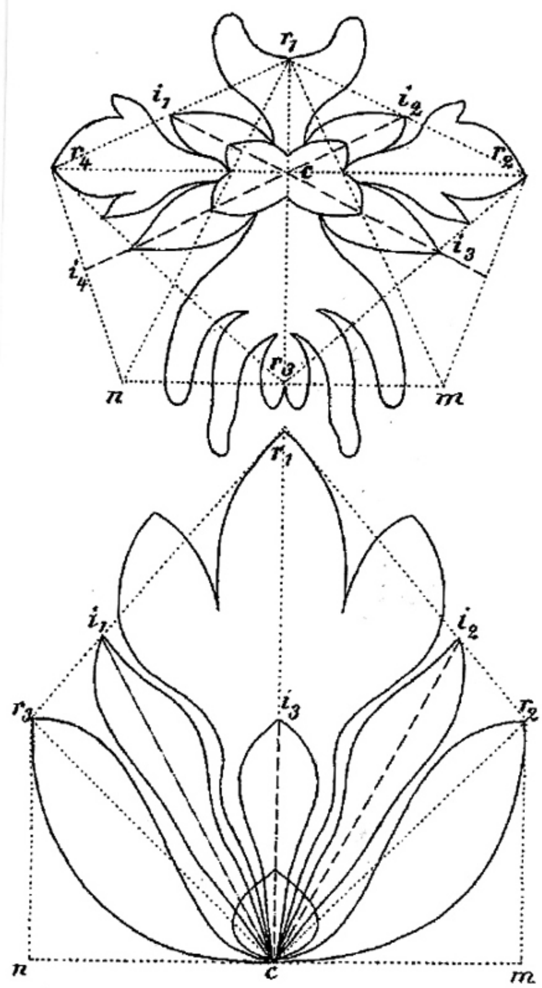
CFD workshop - conception, fabrication, digital - is an opportunity to challenge the process of design to making. From the imaginary form to the physical one, the aim is to handle with the form in terms of its concept, construction and assembly characteristics as well as CNC facilities.

2 Nancy's Context:

The City of Nancy played a prominent part in the Art History, especially during the Modern Style period, called Art Nouveau in France. The "Ecole de Nancy" movement, "School of Nancy" movement, is one of the two French modern style trends. Between the end of the XIX century and the beginning of the XX century, artists and architects derived their idea from the natural and organic forms, linking this design process with the new production methods and the material features. Ornament was no longer incidental decoration but a part of the building itself. The scientific paradigm of this period and the way the nature was analysed, showed and documented, largely participated to the emergence of the Modern Style. The decorative element was no longer defined by its nature itself but in accordance with the image of this nature as promulgated by the culture of science. The understanding of this tamed nature went through the identification and representation of the symmetrical relationships between elements (Haeckel, 2007). Moreover, the shape characteristics were subject to the production methods and materials behaviour. Basic patterns were derived depending on the different types of application and production techniques (Olaf Breidbach, 2007). Nowadays, the ornament question is reviving in contemporary architecture through the use of digital technologies. Kai Strehlke (Strehlke and Loveridge, 2005) presents a work made with students in the exploration of ornament redefinion. He lists three main generative methods, nurbs sculpting surface, programmed surface and images derived surface, and exemplifies the possibilities.

Jean Prouvé, native from Nancy, is another major actor of the Architectural History. During the middle of the XX century, he largely contributed to the renewal of the architectural language through the integration of industrial procedures and techniques. Familiar with the metal, he explored both furniture and building, through the production of structural systems or envelope components. He was very attached to the experimentation and he considered the material feature knowledge as one of the main design principles. This material knowledge was acquired through its manipulation. Especially, he considered the use of physical prototypes as a design method. Jean Prouvé was very implied in the fabrication processes and he involved industrial techniques into the field of architecture. He especially worked on the home standardisation and home industrialisation production in the context of the after Second War reconstruction. Nowadays, Prouvé's way of working is updated by digital fabrication technologies and mass customisation production. Here the object takes place in a continuous formal variation, the designer is working on an aspiring shape variation and the final object symbolizes a significant instant of the process (Kolarevic, 2005).





Door, Prouvé's project. Light effects and variation

Geometric and symmetric interpretation of natural form.

3 Educational approach:

CFD is a one-week workshop with graduate students from the Architecture School of Nancy in France that took place in February 2009. Twelve students, divided in 4 groups, were asked to lead a project from the conceptual idea to a small performance model. The starting point of the design process was a picture of a natural phenomenon, organic or inorganic construction. This picture was supposed to stimulate the imagination and the creativity of the students. This approach was established on the analogical thinking, the visual culture and the visual ability of a plastic interpretation based on a picture inspiration. The analytical question was then tackled through the explicit formulation of the morphogenetic and constructive characteristics. The image should be interpreted until a physical reality. The generative components of the shape should be identified and understood in order to digitally model them. The form composed by the adjustments of unitary forms, the growth of the form, the form in motion, the continuous deformation and isomorphic transformation are some examples of a morphologic look. Based on this exciting image selection, students were free to define a program, formulate a purpose and choose a site for the project. The second stage of the exercise aimed at a constructive interpretation. Students were helped by the formal taxonomy supplied. Finally it was asked to include the whole thickness of the architectural question. Physical qualities, sensitive affects, social effects and usage features should be argued.

3.1 Lectures

Students had no specific knowledge in digital fabrication and we started the week by four lectures. The first one was an introduction to the digital fabrication approach, methods, machines and processes. We presented the different digital fabrication techniques, the additive and subtractive methods and we respectively illustrated the different kind of existing machines: 3D rapid prototyping, lasers cutter, water cutter, 3D milling, cutters and engravers. We gave some examples of the continuum process associated to a file to factory approach. These examples were extract from previous experiences led in the architecture school of Lyon and Grenoble, especially with the European Learning Project Continuum F2F. We epitomized the digital process, from the digital model of the object under conception, to the constructive interpretation of the shape, and finally to the set up of fabrication files including the tool paths definition and the nomenclature of components. We exemplified the importance of convoking at the early begin of the design process the material behaviour and fabrication constraints.

The second lecture presented a categorization of the architectural formal vocabulary in which each shape family was associated with its constructive characteristics and constraints. We identified five “Morpho-types” in function of the scale and the geometry of the shape’s components, of the material and products used, of the structural system behaviour and of the assembling and fabrication methods. These families are stacking, tilling, mesh, braces and membranes; moreover they were divided in subgroups.

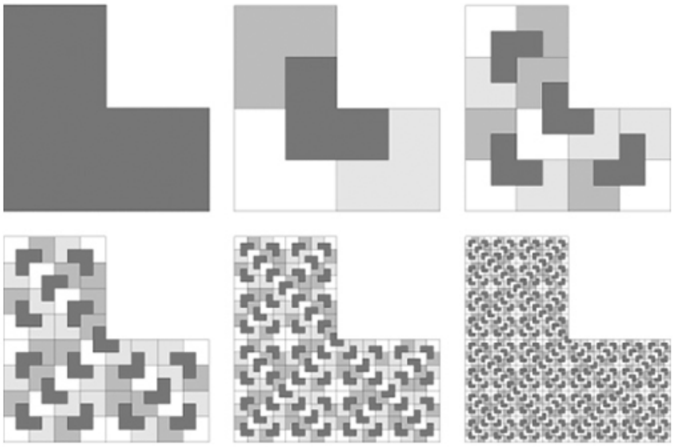
- The stacking refers to the superposition of horizontal evenly or not plans. Corbelling generates the form in elevation. The friction between the elements cancels the horizontal forces. A distinction could be made between modulate stacking and layering.
- The tessellation refers to the splitting up of a structural surface with similar elements, which fit together avoiding an empty space between them. A distinction could be made between facets, waffles and folds tessellation.
- The mesh is a grid of a bars network. Bars are fixed together by knots and are especially subject to traction and compression. The mesh is located in the plan of the surface or parallel with it. Edges, lattices and braiding make up this category.

- The brace is a composition of various structural elements that build a three-dimensional shape. This shape could receive an envelope surface. Braces are normal to the surface. Frames, arches and grids extend the category.
- The membrane is a continuous structural surface made with linear (planks) or surface (panels) elements but assembled with no angle. Vaults or shells represent a variation of the membranes.

The third lecture offered different assembly solutions and knots sorts. These tie principles were organised in six main categories: free union, frivolous ligature, interlocking, supported union, assisted union and intimate connexion. Each of these categories was subdivided. Straddle, ligature, padlock and fasten composed the free union family; ligature and sew the frivolous ligature one. Interlocking, mortise and tenon, wedge and splint made up interlocking category. Connect and tighten made distinction inside the supported union group; link-pin, cotter, screw, clasp, bolt extended assisted union and direct stick or assisted stick represented intimate connexion.

The fourth lecture was about the geometric interpretation of natural shapes. The digital geometric concepts and the form production strategies, that is to say the adjustment, combination of unitary forms, or the continuous shape deformation through the use of morphologic operators like twist, stretch, pinch (…), were linked to natural morphogenetic processes. The necessity of a geometric interpretation of the natural shapes in the context of digital modelling was demonstrated. Symmetric arrangements, algorithmic growth and the mathematic of the natural form were illustrated. Fibonnacci sequence, fractal description, recursive processes, Voronoï tessellation were some of the given examples. Cecil Balmond (Balmond, 2008) explored the potential of nature and science as an open book able to highlight geometric realities.

Algorithmic Growth : Geometric interpretation of natural growth.



Recursive sequence.

3.2 Resources

To lead the design, the students had directly access to different kind of resources. First, in order to stimulate their creativity they could pick an image from a library composed of two hundred pictures ordered by types: animals, trees, art, corals, shells, water, snow, natural forms, plants, rocks and crystallography.

The following software were used: Maya© and 3DStudio Max©, mel and maxscript associated to the conceptual modelling, Autocad© and Illustrator© dedicated to two dimensional drawings and adjustments, Artcam© concerning fabrication files setting, WinPC© in charge of the post processing and the machine driving.

Moreover, a library of mel and maxscript functions were available: automatic Boolean operations and transformation, random positioning, recursive tessellating, Fibonacci sequence, multiple sectioning, unfolding facets, automatic “half-wood” assembling generation.

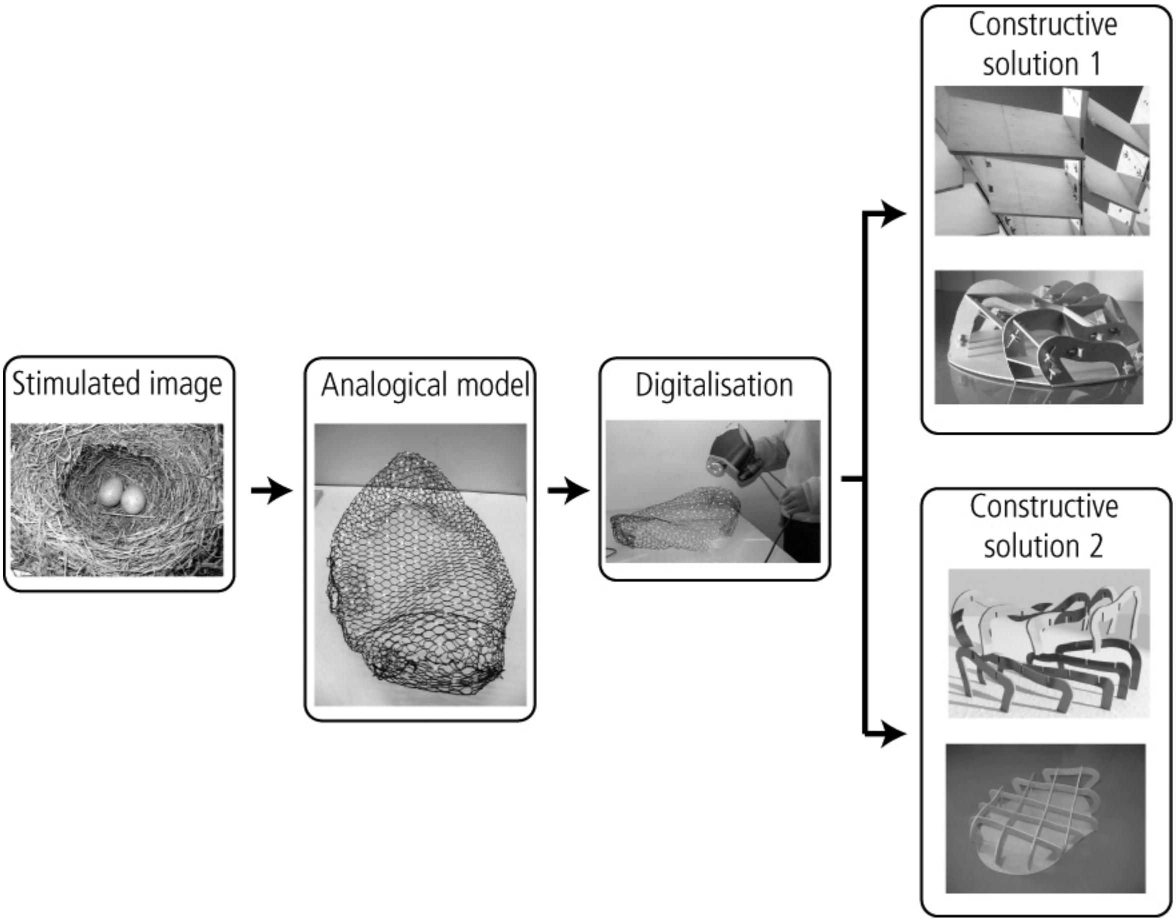
Finally, a 3D milling machine was installed. This machine has an 800 x 750 mm cutting area. From 3 to 8 mm diameter wood wicks and 3 mm thickness MDF panels were available. This CNC machine is part of the Digital Fabrication Lab of the Architecture School of Lyon.

3.3 Work in progress

The first half-day was dedicated to the lectures and general information. But very quickly students started to work on their own project. Between half a day and two days were conceded to conceptual design, then each group, based on temporary reviews, had to prepare its fabrication files. The last two days were devoted to the panels cutting, fabrication and assembling. The generation of Numerical Control (NC) machine code was done with traditional CAM software such as Artcam©. The files setting up were important during this phase and students had to defined cutting paths, cutting tools and specific machine parameter. Due to the lack of time, students were supported during this phase.

4 Case study

The following project is interesting because of its go and back between atoms and bits. The starting point of the project was a picture of a bird nest: beginning with this evocative image, the students projected a small museum evoking a natural form. They started by hand modelling a grilling in order to obtain the desired shape. Then they proceeded to the digitalization of the physical shape with the help of a portable handheld 3D laser scanner. After an optimisation phase of the point cloud data, two constructive hypotheses were explored.



The first constructive solution was based on an assembly at "half-wood" of series of arches. This arches grid was made with the use of a parametric script that allows defining distance between two beams, beams' thickness and depth fitting. Geomagic© software and 3DStudio Max© with maxscript were used to design this structural envelop.

The second constructive solution intended to keep the notion of random in the final structure, as it is present in a natural bird nest. In order to evoke this, students evenly placed vertical plans and thus defined structural arches. Then they randomly displayed series of struts. Here, all the drawings were handmade in Autocad©, no automatic procedure was implemented.

5 Discussion

Our experimentation remained at the scale of model production. Nevertheless, it seems very important to explore the digital production at the one to one scale. First because materials behaviours will change, the linear transposition from model to final project is not possible, and second because the physical experimentation of the space and effects generated are really instructive. Nevertheless, such experimentations require larger machine capacities, a dedicated workshop, equipments and technician competences. Such equipments are available in architecture schools like ETH (Zurick), University of Oulu

(Finland), Harvard University (USA) or Les Grands Ateliers (France), and in the next future in Nancy with the Innocité project.

We started to build a tools box putting together scripts and functions but we have to enhance it. Supplying students with predefined scripts is fruitful and enables to increase in return the available tools. Our aim is to link together our morpho-types with their corresponding assembly solutions and thus implement scripts that allow a parametric production of respective components.

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Design, Fabrication, Digital

Between digital design and digital fabrication

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Abstract: *This paper represents an educational practice aiming at analysis of the link between digital design and digital manufacturing. CFD (conception, fabrication, digitale) is a one week workshop with graduate (master recherche) students of architecture school of Nancy. Having passed the first semester with a focus on modelling principles, computational logics and formal data representation, students are well prepared to apply them all in the process of form generation. The exercise is based on experimenting with new approaches in computational form generation interweaving geometry, aspects of construction and fabrication technologies.*

Keywords: *CAD/CAM technologies; form generation; digital design; digital fabrication; constructability; architectural education.*

Introduction

Since the early applications of computer science in architectural design, this interdisciplinary cooperation has greatly developed. Started from graphic visualization tools, the real role of so-called computer aided architectural design tools was limited to assist the presentation of final results. The insufficiency and the incompatibility of these applications with the essence of the design process were since discussed.

Due to the use of advanced computing techniques in design, a new generation of tools was brought about. The evolution from presentation tools to "generative tools" provided architects with the opportunity of extending computational power throughout the whole process of design from early stages to the end. While new tools are capable of dealing with digital geometric models supporting algorithmically generated forms, they seem to be impotent to encompass other kinds of data related to the process of form generation. So a holistic approach containing fabrication information is required.

This paper explores the relation between architectural morphogenesis and information necessary to support the process of construction.

Architectural Morphogenesis

From an etymologic point of view, the term Morphogenesis, coined around 1890, derives from the Greek "morphe" which means shape and "genesis" which represents creation. Putting them together, it denotes the process of development and formation of a form, a structure or a system as well. It arises from procedural changes during the process. Biological morphogenesis refers to the shaping of an organism through differential growth of "embryo".

D'arcy Thompson (1967) was one of the pioneers to apply mathematical and physical data to the process of biological growth. In "on growth and form" he discusses the generation of form through a comparative analysis of inter related states of change, each containing the spatial data (three dimensional coordinates) of the next. This study reveals the potential of geometric models to deal with both biological and architectural morphogenesis.

Biological morphogenesis differs from the architectural one in two different but related facts. First of all the biological growth is a dynamic process entwined with the concept of time. "Morphogenesis is the creation of forms that evolve in space and over time" (Micheal Weinstock, 2004). Secondly, the biological growth is interwoven with the process of physical materialization, while in architectural morphogenesis the last one is distinctly separated from form generation. A third point would also be added to these; feedbacks have significant role in the process of morphogenesis. In the case of architecture the environmental feedback includes also the specificities of cultural context. This essay is focused rather on the second point; materialization.

The discrepancy between design and fabrication processes in architectural design is somehow reflected in a distinction between CAD and CAM tools. While CAD tools provide us with digital 2D, 3D models of generated forms, divers' aspects of fabrication are usually taken into consideration when the whole process of design is worked out. "*One danger with using purely geometrical design tools that are not tied in with any physical simulation tools or any verification software for the intended fabrication process is that it is easy to forget the physical aspects of the emerging construction*." (Sequin 2008)

This exercise would be an aid to investigate the idea of constructible form generation.

CFD (conception, fabrication, digitale)

CFD (conception, fabrication, digitale) is a one week workshop with graduate (master recherche) students of architecture school of Nancy 2^{nd} – 7^{th} Feb 2009. The main issue of the exercise is to deal with tree parallel matters at the same time: the process of form generation as a result of the combination of certain geometric operations, possible ways of fabrication based upon a classified group of methods employed in the process of construction and a process of digital manufacturing based on CNC technologies. Geometric description of the model is as much in relation to the idea (represented via a selected image) as the construction and assembling techniques. Students were free to think of different programmes for final results.

The process of form generation of the exercise is inspired by "école de nancy" (Nancy School) which has been developed as the spearhead of "Art nouveau" in Nancy, France around 1900. The original aspects of the école de Nancy lies in the fact that there is a close bond between art and industry. Using plants and animals as a main source of inspiration, the aim is to integrate form, material and technique (Figure 1). Our inspiration from "école de Nancy" concerns rather its specific approach to design than its formal results.

The first step starts with choosing an image, containing two or three dimensional shapes, as the source of inspiration. Students were supposed to figure out geometric operations involved in the process of form generation. Here the task is to extract geometric operations and to combine them into a series, conducting the modeling of the chosen form. Geometric modelling was done in MAYA, other software were also used if needed. A database of images, mostly from nature, containing different kinds of trees, plants, cauliflowers, animals, sea animals (seashells, lobsters, crabs …), is provided as a source.

Selection and composition of chosen operations relies also upon specific method of construction. Analyzing a number of erected projects such as saint

Loup chapel (Switzerland) designed by Mondada and Localarchitecture (*figure 2*), *Centre Pompidou* (Metz, France) by Shigeru Ban (*figure 3*), *Napier University* (Edinburgh, Scotland) designed by Richard Woolsgrove (*figure 4*) and *etc.* certain methods of construction are revealed. Pilling up, tessellation, timber framing, ribs, shell-shaped surfaces, entangled ribs … are methods undertaken by architects. This part of the exercise is supported by different scripts, developed and implemented, able to unfold a tessellated surface, to slice the 3d model in two perpendicular directions and also to create the intersection of two slices.

This step is supposed to investigate the degree of constructability of geometric operations.

The last step is to fabricate forms which are already modelled in Maya. A package of CAM and CNC software (ArtCam and WinPC-NC) is used to cover the linkage between digitally designed forms and the machine in order to manage the process of rapid prototyping. A 3-axis Milling machine is used for this. At the same time, students were also supposed to consider different modes of assembling.

Analysis of projects

In order to analyse the continuum of design to manufacturing, two examples are described step by step.

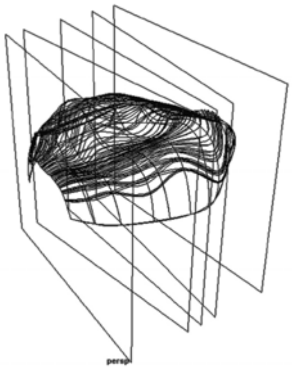
The selected image as the inspiration source for the first project was a "nest", so the first step was to create a model in the form of a nest. For that, two possibilities were explored; digital modelling through MAYA and creating the final surface by manually deforming a piece of wire mesh.

Figure 1 (left)
The canopy of the chamber of commerce and industry Nancy, France

Figure 2 (right)
saint Loup chapel, Mondada, Switzerland

Figure 3 (left)
Centre Pompidou, Shigeru Ban, Metz, France

Figure 4 (right)
Napier University, Richard Woolsgrove, Edinburgh, Scotland



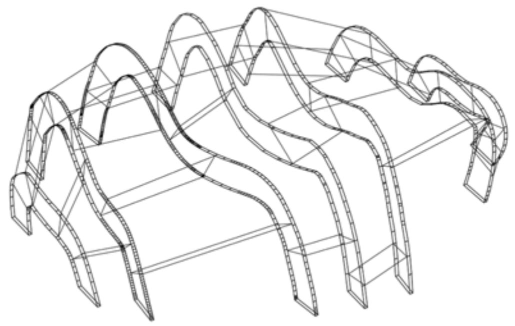


Figure 5 (left)
Cutting the deformed surface by vertical plans

Figure 6 (right)
Rectangles created randomly between curves

As one of the objectives of the exercise, geometric description of the model was supposed to be based on other considerations. Firstly, the choice of a nest as a mental image refers to a series of randomly positioned pieces of wood. Secondly the selected construction method was possible either trough an entangled (crossed) rib mesh or by bracing two pieces with another wooden piece.

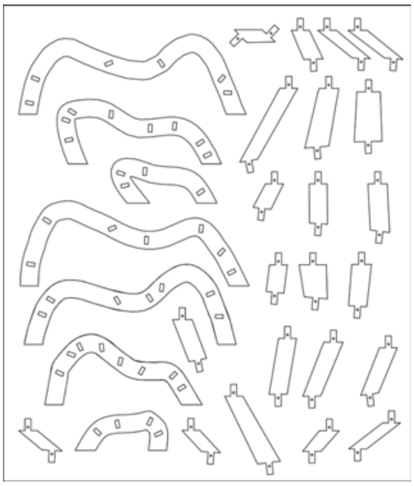
These issues, the concept crystallized through a mental image and also the desired construction technique, can absolutely affect the process of form creation and geometric modelling. A nest might be seen as a randomly deformed surface while aiming at a specific construction technique such as the two explained above, it might not be limited to a sole envelope. Each geometric element (point, edge …) would respond to specificities of the constructional method. This demands a new adaptation of the geometric model based on its constructional identity.

In the case of the first way of modelling (a digital model in MAYA), the nest was the result of the intersection of two series of ribs. To create the first series a deformed surface was needed so that the curves get the correct deformation. After trying different possibilities, "lofting" seemed to be the most appropriate strategy to achieve the wavy amorphous surface of the nest. This surface is created so that we achieve the entangled rib mesh. These curved ribs are the result of the intersection of some random vertical planes, which are not parallel, and the original surface of the nest (*figure 5*).

First series of curves (intersection of deformed surface and vertical planes) created in MAYA are then exported to AutoCAD to have more control and precision on final design. In other words second series of ribs and holes were created in AutoCAD. First curves were extruded to create bands of 3 centimetre width. They are later cut out from a 0.3 centimetre thick wooden board. Series of rectangular holes should be also cut out from these curved strips through which second series of ribs will be connected to first ones. The 3 centimetre width was chosen to avoid the tin wooden strip to break and also to reserve enough space for holes.

To control the connection between first and second series of ribs, second ones were first drawn, in perspective view, between first ones (*figure 6*). Second series are in the form of rectangles with different dimensions. To have the two dimensional outline of both first and second series of ribs, an operation of alignment was applied on them. Each rib of second type must contain two small pieces on its sides via which it is connected to two ribs of first type.

The last step is to export this two dimensional figure to "ArtCam", so that it be cut out from wood boards (*figure 7*). Finally a third piece of tin wood is



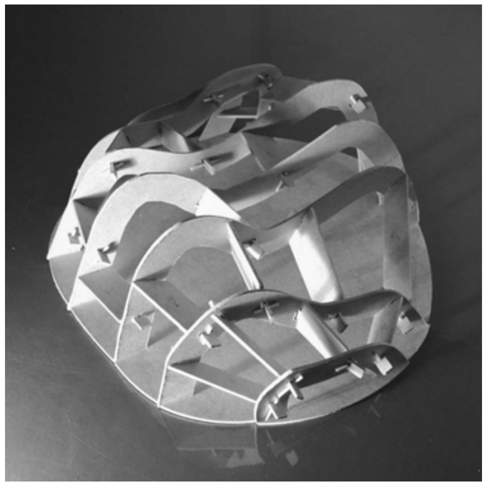


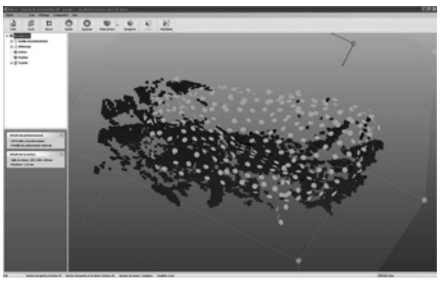
Figure 7 (left)
Final setting of pieces ready to cut

Figure 8 (right)
The assembled final model

used to brace and fasten them (*figure 8*).

The same project was realised in another way. The geometry of the nest was not digitally modelled, but created out of a wire mesh, deformed manually. It was then captured with a laser scanner (handyScan. EXAscan). The resulted data cloud (*figure 9*) was then converted to a polygonal mesh surface (*figure 10*). This was done in "geomagic 10". The surface was then exported to MAYA. It is supposed to be the base to create entangled (crossed) ribs. To this a script was applied which is able to cut the surface in two perpendicular directions and also to draw a precise figure of the connection of two perpendicular crossed parts (*figure 11*). The result is then exported to ArtCam to be cut by the milling machine (*figure 12*).

The second project was inspired by a seashell (*figure 13*). The process of modelling was done in MAYA. The whole surface of the seashell was modelled through "lofting". It was then cut horizontally, via Boolean operation, to facilitate the stability of the final result on a flat plane. A helix and a circle were used for lofting. In other words the triangular subdivision of the seashell surface was the direct result of the number of segments of the circle. This adjustment was related to formal aspects of the surface



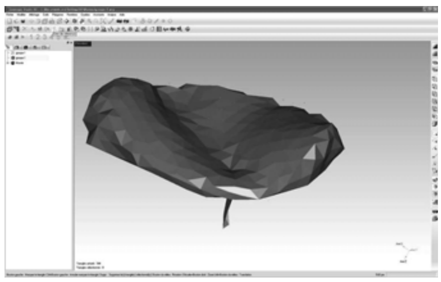


Figure 9 (left)
Data cloud captured by scanner

Figure 10 (right)
Polygonal surface created in "geomagic"

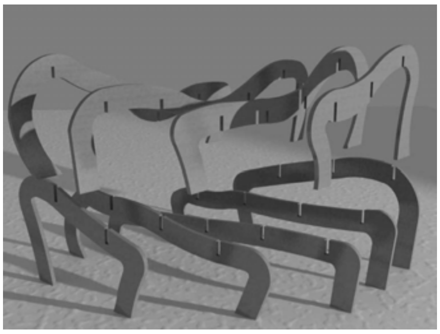


Figure 11 (left)
Surface sliced by the script

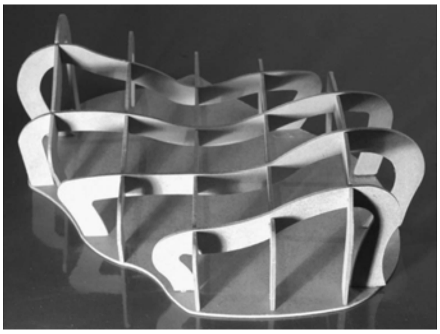


Figure 12 (right)
Final result, assembled

as well as construction and assembling techniques (*figure 14*).

This project was supposed to be constructed with a series of wood panels connected together by their contours, in a way that they can be decomposed, assembled and disassembled. Each panel corresponds to one triangular facet of subdivision and each facet is connected to one beside by sewing.

The subdivided surface of the seashell should be unfolded, so that facets can be cut out from wood panels. For this a script was applied which was able to put facets one beside the other and put a number on the model as well as the unfolded facets. It is necessary to have numbers on both model and unfolded facets to control the final spatial arrangement of the model.

To deal with the assembling method, series of holes should be drilled all along the three edges of facets. Radius of holes was equal to the drill's one; 0.3 centimetres but the distance between them was adjusted at random, about 1.8 to 2 cm. The distance between holes and each edge was adjusted in a way to prevent panels from breaking after removing holes; this was again affected by the scale of the model. This part of model (assembling design) was prepared in AutoCAD.

As explained above, the script was just able to unfold the surface and put facets one beside the other, but we would also need to know which edges of each two panels should be connected (sewed) together later. To do that the unfolded facets, were reconnected to create a two dimensional flat model

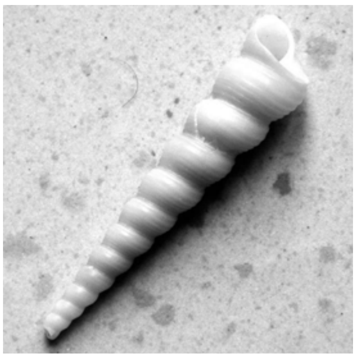


Figure 13 (left)
Source of inspiration; seashell

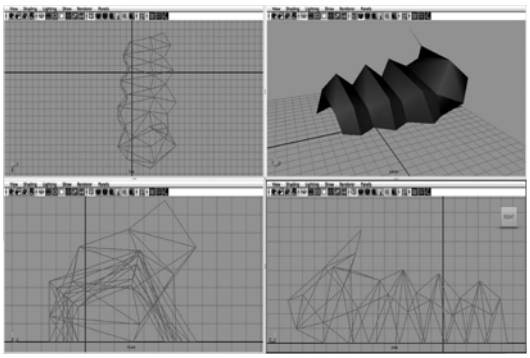
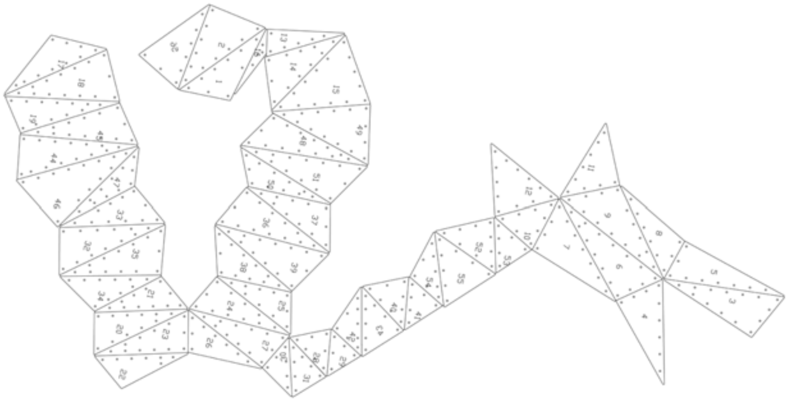


Figure 14 (right)
Geometric modelling in MAYA

Figure 15
The subdivided surface was unfolded. Facets were then reconnected to create a 2D model



of the seashell surface (*figure 15*).

Passing through ArtCam, panels were cut and then connected by the string passing through holes (*figure 16*) and (*figure 17*).

Conclusion

It is obvious that construction methods widely affect the geometrical description of a form, what is digitally modelled will not match the constructed form thoroughly. Considering the construction methods during early stages of design can provide an improvement in architectural morphogenesis.

Although specific aspects of geometric modelling such as position and dimension of elements were supposed to be adjusted in relation to construction or assembling considerations, they were widely affected by the scale of the model. Certain issues are not reflected nor treated in the model the same way as they are in reality. There is not enough

Figure 16 (left)
Assembling panels by string

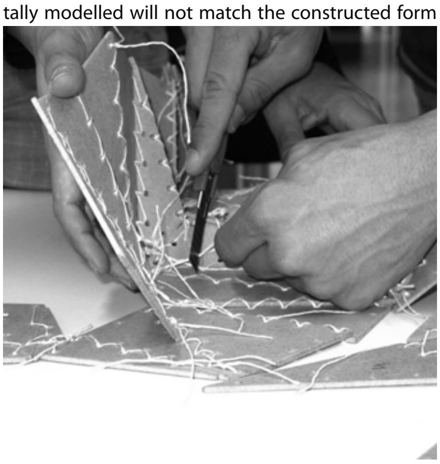
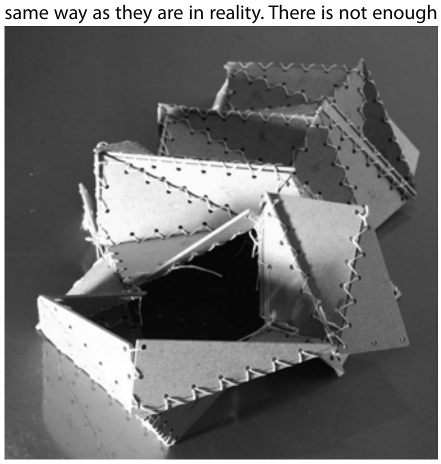


Figure 17 (right)
Final model



fidelity between model and the real object.

In the first project, the position of holes on the curves of fist series was found randomly. The width of curved bands was 3 centimetre to avoid them to break, but this was totally dependent on the model scale. In the second case study, position and dimension of holes should be based on assembling technique as well as material properties. Even the degree of subdivision should be based on construction criteria.

Geometric operations and construction related issues were both handled in different software, while specific assembling methods were poorly supported by these. The important point is that a model represents a final "finished" object which can support the spatial order and composition of the object, while we need often to know the chronological order and composition of components. A model capable of representing the object "being created" or "being completed" would be more helpful.

The objective of the exercise was to investigate the links between different stages of development of architectural form during its life. Paradoxically to the continuity of data during the process, the link is supported by a discontinuity of software.

Acknowledgements

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A Genetic Algorithm for use in Creative Design Processes

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Abstract

This paper deals with natural growth mechanisms applied to architectural design processes. We implement a genetic algorithm as part of a digital tool to be used in the creative design process. This evolutionary process is evaluated by means of environmental parameters, passive solar qualities and the designer's individual requirements. A morphogenetic process is put forward, based on a "metamorphosis strategy".

1 Introduction

Phylogenies symbolize the evolution of species: mutation, crossover and natural selection govern this evolution. These concepts provide a guide to the development of artificial and digital devices capable of simulating natural mechanisms, and bringing into being new properties and qualities. Evolutionary design has its roots in computer science, design and evolutionary biology. It is a branch of evolutionary computation, which extends and combines CAD and analysis software. It does not hesitate to borrow ideas from natural evolution.

In this paper, we deal with morphogenetic mechanisms applied to architectural design. We consider that evolutionary systems could help to guide designers in creative directions. We were not looking for an organic or genetic form, but for digital tools inspired by genetic mechanisms capable of assisting and supporting design projects. We feel that such tools could be conducive to architectural creativity. We focussed, in particular, on the initial phases of the design process.

2 Related work

2.1 Integral evolutionary design

There are numerous examples of evolutionary algorithms: genetic algorithms, proposed by J. H. Holland in 1975, evolution strategies, proposed by P. Bienert, I. Rechenberg and H. P. Schwefel in 1960, evolutionary programming, proposed by L. F. Fogel in 1966, and genetic programming, developed by J. Koza in 1992.

Genetic algorithms are probably the best-known evolutionary search algorithms. Starting with J. Holland in 1975, whose aim was to explain the adaptive processes of natural systems and to design artificial systems based on them, there have been several applications of genetic algorithms. Caldas (Caldas and Norford 2003) used a genetic algorithm to optimize construction budgets by minimizing HVAC, lighting energy and construction costs. Malkawi (Malkawi et al. 2003) offered a Java environment using a genetic algorithm as an evolutionary algorithm and a CFD performance as an evaluation mechanism. Nishino (Nishino et al. 2001) provided an example of an interactive evolutionary computation applicable to a creative design process. One of the most famous authors in the field of the evolutionary architecture is John Frazer, who has been involved in the use of genetic techniques for building envelope designs since 1968, and the use of genetic algorithms since 1990 (Frazer et al. 2002). He explores the possibilities of expressing architectural concepts as generative rules so that their evolution and development can be accelerated and tested by the use of computer models.

In general, evolutionary design can be divided into four main categories: evolutionary design optimization, creative evolutionary design, evolutionary art and evolutionary artificial life (Bentley 1999). Here, we are essentially interested in creative evolutionary design and evolutionary design optimization, whose overlap is usually known as "integral evolutionary design".

Evolutionary algorithms are traditionally used to solve optimization problems. In addition, they can be used as a design aid. The evolutionary approach is a generative testing method that fits the procedures for design synthesis and evaluation in the design process. The characteristics of the approach are:

- A pool or population of design solutions, rather than a single solution.
- The selection of individuals according to their adjustment to the fitness function.
- The generation of new solutions through mutations and crossovers of previous elites.

With the advent of new technologies in the field of evolutionary design, the designer's role shifts from that of a creator of individual styles to that of a meta-designer or creator of an entire style family (Soddu 2004). Design-as-Product or Ideas-as-Product, as defined by Soddu, is focused on the act of designing the species representation or "DNA" of a designed object. In addition, changes in design can be used to stimulate creativity (Todd and Latham 1992). Large numbers of evolutionary steps can be generated in a short time, and the emergent forms are often unexpected.

2.2 Morphogenesis

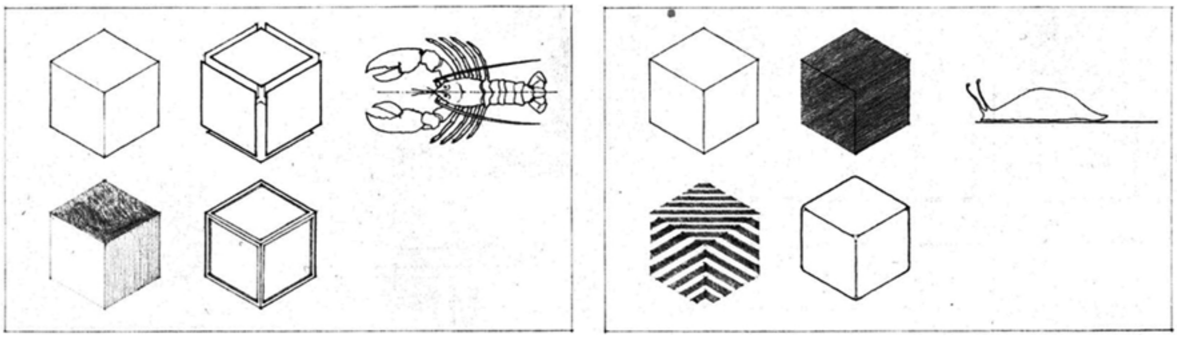

Figure 1. Strategies of morphogenesis

Work done by Ching (Ching 1979) (Figure 1) on the conception of forms in architecture has made it possible to identify two main strategies for the production of form. The first can be metaphorically represented by a lobster, and consists of creating forms through adjustment and combination. The original form is composed of unitary forms that can be added, juxtaposed or superimposed. The second is represented by a slug, the original form undergoing morphological but not topological modifications, with operators such as twist, stretch and pinch. We will refer to this as “transformation through metamorphosis”.

Wetzel (Wetzel et al. 2006) offers two classes of morpho-semantic operators: unitary operators that act on a single object, and binary operators that act on two or more forms. The unitary operators cover isometrics (translation, rotation, symmetry) and homothetic transformations. Transformations on a higher scale, known as “modifiers” can be used to obtain the desired shape. These are: bending, tapering, skewing, twisting and stretching.

Natural growth is an expression of morphogenesis. As far as biology is concerned, the understanding of a form implies the description of a generative process, i.e. a type of morphogenesis. We based our morphogenesis transformations on strategies of metamorphosis. We applied certain “modifiers” in a recursive, successive way in order to transform our initial pattern, and thus to explore a solution space. This strategy guided our morphogenesis. Rather than looking for the solution of the starting problem, the idea was to define a program whose execution would lead to the solution.

3 Experiment

3.1 The development environment

We focussed on the initial phase of the design process, where the designer is looking for ideas, with reference to Gero (Gero and Maher 1998) regarding the matching of the generative process to the architectural design process. This paper deals with the question of creativity, and the definition of the design process.

In our proposal, a generative process is defined as an evolutionary process and a solar passive fitness condition. This means that the designer is looking for an appropriate formal means of pushing forward his work-in-progress. Figure 2 gives an illustration of a possible population.

This experiment used 3DS Max® software, maxscript being used for scripting and encoding. A genetic algorithm was scripted in maxscript. The final experiment is still in the process of being developed.

Environmental parameters were used to drive the evolutionary process. Passive solar evaluation was based on the Unified Day Degree method (UDD), which is embedded in maxscript.

Figure 2. A possible population

3.2 Initial Pattern

The initial pattern matches the definition of an elementary genome, that is to say the first individual (Figure 3.). Here, the user is initializing the procedure. The initial pattern is represented by a schematic geometric description, a sketched volume, a primary envelope containing constraints not yet explicitly described, such as the plot dimensions, the desired surfaces, the personal formal intention of the designer and the mental representation of the designer. For our first experiment, we used a simple box of fixed size.

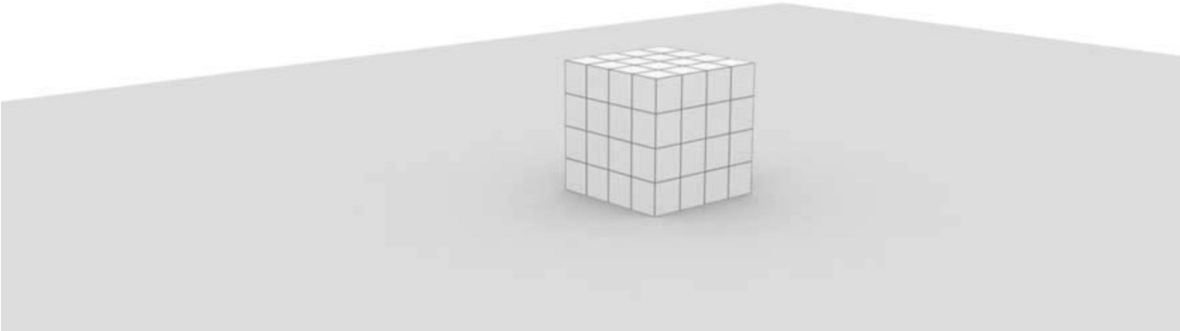

Figure 3. Initial pattern

The following three parameters played a key role in the solution: the overall dimensions, the overall form and the topological description (the number of segments, the number of vertices and the number of faces). They did not evolve during the evolutionary process.

It is clear that the first two parameters were highly influential. The influence of the third one was less direct, but we might suppose that the more defined segments there are, the more facets will be manipulated, and consequently the more continuous the deformation will be.

3.3 Shape exploration

The shape exploration was based on transformations through metamorphosis. Unitary operators were applied; in 3DS software they are called "modifiers". We used 5 main modifiers: bending, tapering, skewing, twisting and stretching. For example, the available parameters for tapering modifiers were: amount (between -100 and 100), curve (between -3 and 3), primary axis (x, y or z), effect axis (x, y or z) and gizmo rotation.

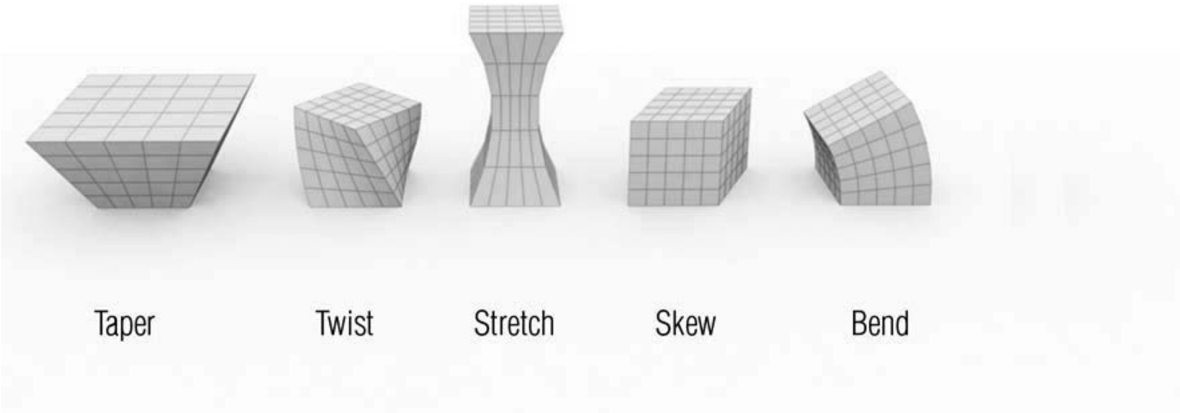

Figure 4. List of modifiers

The shape explorer takes the initial model as an input that triggers shape exploration, and automatically derives various shapes by simulating natural evolution through crossover and the mutation of genomes.

3.4 Material exploration

The material explorer makes it possible to modify the properties of each facet, regarding the opacity and the thermal resistance coefficient. These physical qualities are stored in an array, and to each facet the algorithm randomly assigns an index which refers to a physical quality. The polygons are labeled, and the evaluation engine then uses properties. This array is the “material chromosome”.

3.5 P-type and G-type

Using genetic algorithms, each individual is represented on the one hand by its P-type, i.e. its phenotype or geometric representation, and on the other hand its G-type, i.e. its genotype, or an encoded P-Type representation. The G-type symbolizes the individual's genome.

In our model, the G-type is based on a derivation approach. Rosenman (1997) makes a distinction between the transformation and the derivation approaches. The derivation approach is based on the use of rules. Executing the G-Type sequence generates a form, the G-Type representing a recipe rather than a blueprint. To go further, regarding the representation and structure of our G-Type, two main chromosomes made up our genome: one was associated with the physical properties of each facet, and we called it the “material chromosome”, while a second represented the description of the shape, and we called this the “shape chromosome” (Figure 5). At any time, the designer had the ability to edit the “shape chromosome” and modify its parameters.

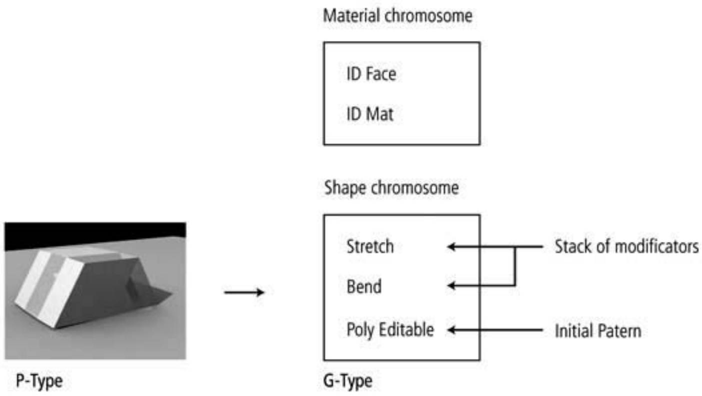

Figure 5. P-type and G-Type translations

3.6 Crossover and mutation

To begin with, a random population was defined. Each individual was evaluated by the UDD engine. Parents were treated two by two, and their chromosomes were cut at a random point, then reconnected (the process being known as "crossover"). One “modifier” of the first parent replaced a ”modifier” of the second parent. Material properties of the facets were combined in the same way. The ”children” formed a new generation of population, and were evaluated once more. The cycle continued until an acceptable result was attained, or a given limit of generations was reached.

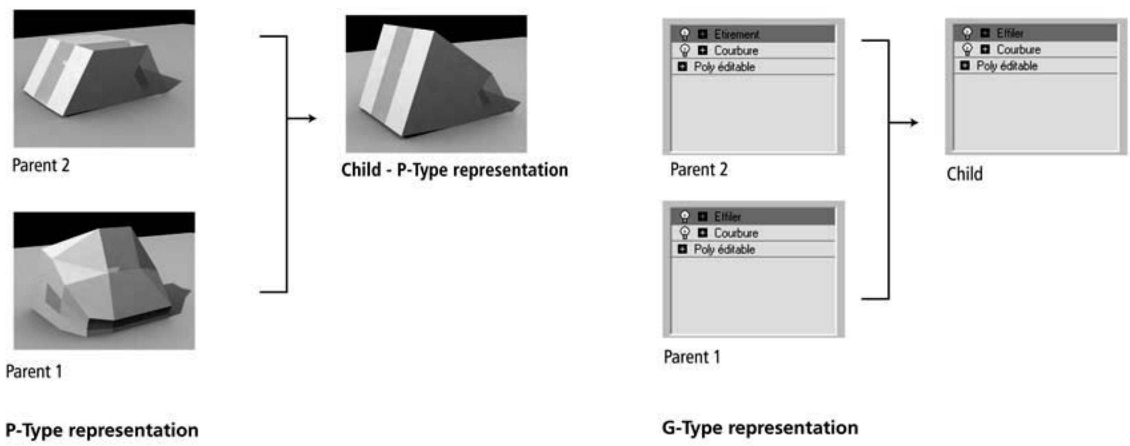

Figure 6. P-type and G-type representation of the shape chromosome crossover

Mutation mechanisms started from a selected individual, then randomly replaced certain parameters of each chromosome. The mutation was placed in a new generation for evaluation and selection.

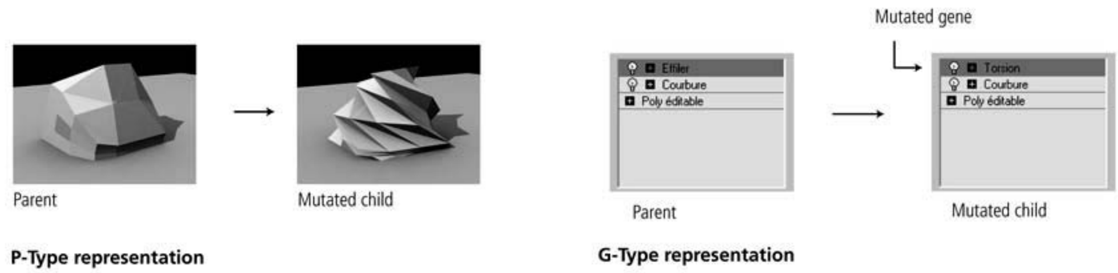

Figure 7. P-type and G-type representations of a shape chromosome mutation

Crossover and mutation can be carried out within a species ("intra-species"), or between species ("inter-species"). In the former case, we changed only the value of the modifier parameters; in the latter, we changed the entire modifier.

3.7 Individual evaluation

The main aim of a non-routine context is to generate suitable forms that are not necessarily optimal, but satisfy a range of customer, social, technical and designer requirements (Rosenman 97). In our example, the evolutionary process was intended to stimulate the creativity of the designer, and to suggest an optimal solution with regard to passive solar properties.

Our UDD engine evaluates passive solar qualities. Its mode of operation is based on the Unified Day Degree method (Figure 8.), which was selected because of the simplification of the problem it provides. At an early stage of the design, all the parameters were not known; some approximations were required. We focused on winter comfort and heating needs.

$D = Ht.Dh(\Omega a)$

D : Heat loss from the building [kWh/year]
Ht : Loss coefficient of the building [W/K]
$Dh(\Omega a)$: Value of degree-day
Ωa : ambient temperature of record

$Ht = Henv + Hrev$

Henv : loss of building envelope [W/K]
Hrev : loss by ventillation [W/K]

$Henv = \Sigma(A.U)$

A : Wall surface [m2]
U : Loss coefficient of surface [W/m2.K]
Hrev : Neglected

Heat loss (D) is offset by free inputs (AG).

$AG = AI + AS$

AG : Free inputs [W]
AI : Internal input [W]
AS : Solar input [W]

$AS = E.Sv.c$

E : Solar radiation function of tilt and orientation [W]
Sv : Glass surface [m2]
c : Transmission coefficient of the glazing

$f = AG/D$

f : Free input divided by heat loss

$\mu = f(f, \text{inertia class})$

$B = D - \mu AG$

B : heat needs [kWh], including free input.

Figure 8. The UDD method

The environmental parameters were stored in an array: solar radiation at a specific angle and orientation panel, external temperatures, internal inputs and inertial classes. Each individual in our population was rated according to heat needs. The lower the heat needs, the higher the individual was rated.

A subjective interaction was added to the evaluation process. The engine displayed the best models that had evolved over the different generations. The user could control the evolution process by exercising selection preferences. The evolutionary process could then be reiterated, based on this new initial pattern. The final evaluation of satisfactory design solutions was to some extent subjective, in that it involved an aesthetic or symbolic content.

3.8 First validation of our genetic algorithm

In order to validate our genetic algorithm, we carried out an initial experiment with a simplified fitness function. The parameters of our genetic algorithm were: the generation number, the elite number, the tournament size, the mutation rate and the population size. Figure 9 shows a pseudo code for the algorithm.

```
generation = 0;
initialize population;
while generation < max-generation
        evaluate fitness of population members
        for i from 1 to elites
                select best individual
        endfor
        for i from elites to population-size
                for j from 1 to tourmanentsize;
                        select best parents;
                endfor
                for k from elites to population-size*(1-mutationrate)
                        crossover parents -> child;
                endfor
                for k from population-size*(1-mutationrate) to population-size
                        mutate parent->child;
                endfor
                insert child into next generation's population;
        endfor;
        update current population
        generation++;
endwhile;
```

Figure 9. Pseudo code for the genetic algorithm

The simplified fitness function was based on the total surface value of the envelope for each individual, which we wanted to minimize. The value of the surface matched the evaluation rank. The lower the rank, the higher the rating. The initial pattern was a simple box of fixed size.

Figure 10 follows the populations through 20 generations, the fourth best parents of each generation being selected, then used to build the elite population. The exploration of the shape uses the Taper modifier to bring about evolution in the population; crossover and mutation are "intra-species". Figure 11 shows the evolution of the simplified fitness function through 100 generations. Four series are studied as a function of the genetic algorithm's parameters. Each configuration can give an optimal solution, but at different levels of efficiency.

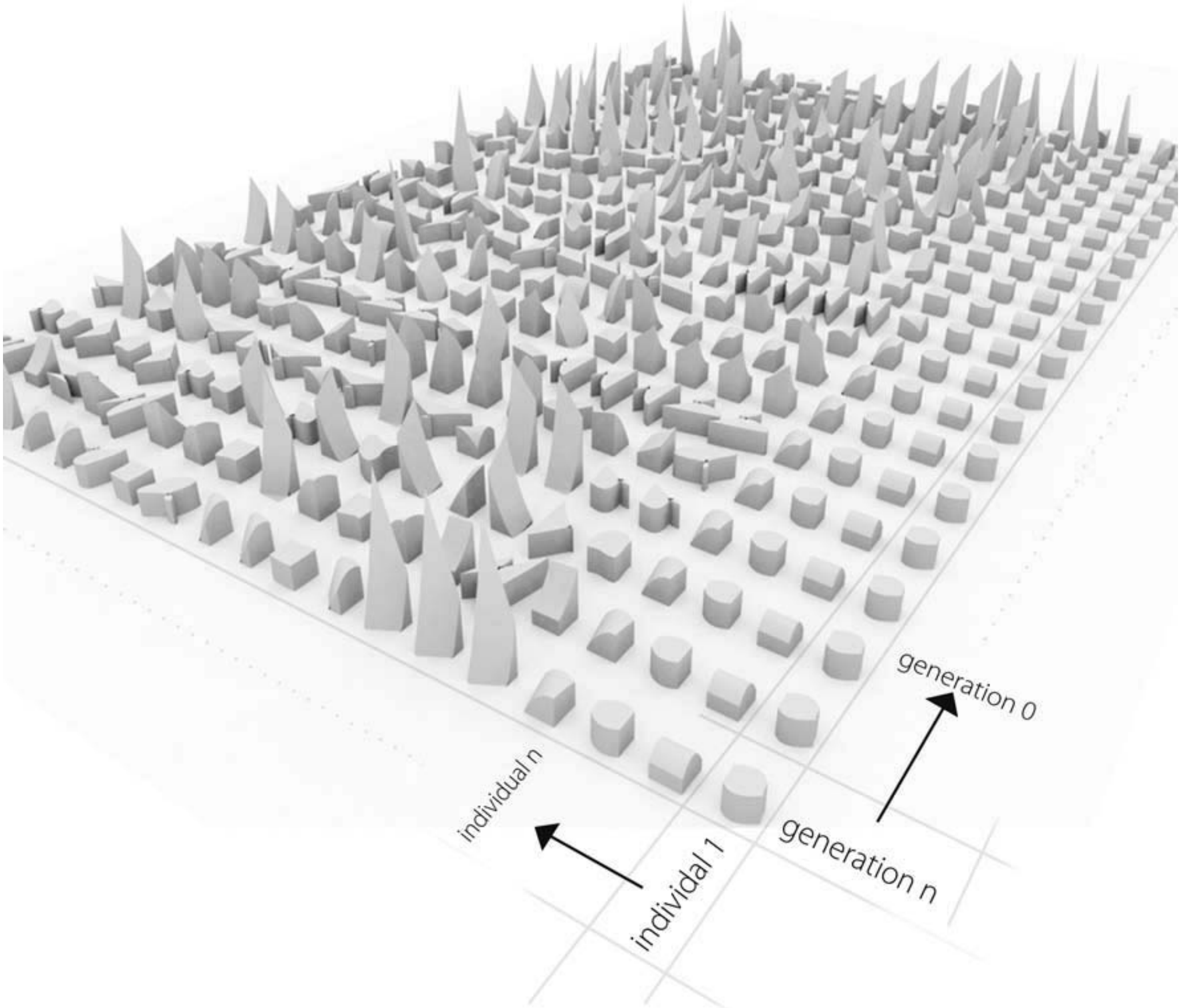

Figure 10. A population over 20 generations

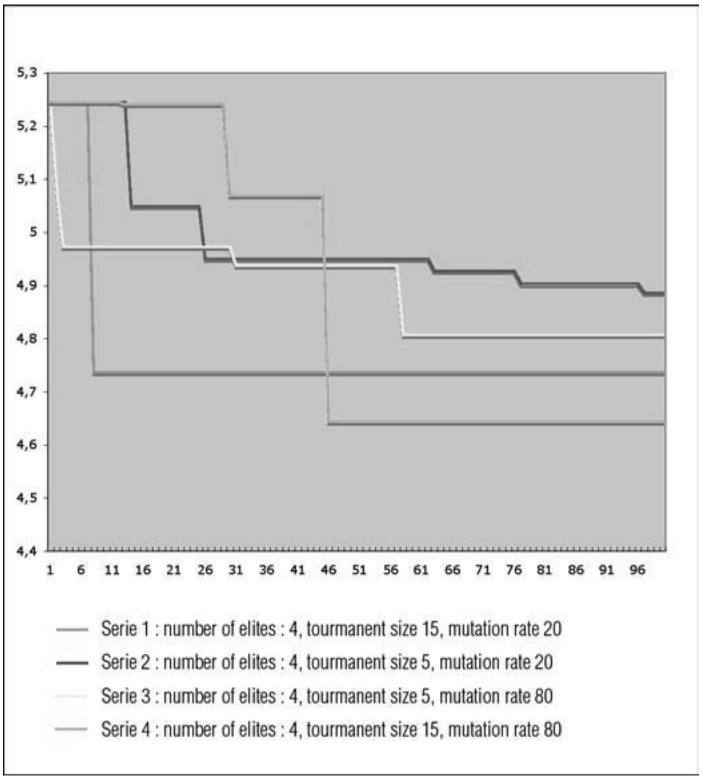

Figure 11. Fitness convergence

4 Conclusion

Having validated the experimental protocol and the efficiency of the genetic algorithm, we are now working on the implementation of the final fitness function. The exploration of the shape takes place correctly, but we still have to define limiting values for each of the modifier parameters, in order to preserve the integrity of the shape. Questions about interactions between the user and the digital tool also have to be examined. An overall representation of all the different generations can be implemented through a phylogenetic tree presentation. This should provide an understanding of filiation relationships. We might also postulate interactive functionalities going back to past generations, and the interactive selection of a grandparent for a new initial pattern.

Environmental parameters can be changed, and design exploration can begin from other locations. Extreme conditions could be used to evaluate the influence of environmental parameters.

Natural processes can be used to develop digital tools applicable to the creative design process, and to generate unexpected solutions. The use of evolutionary processes marks a change in the way computers are used: designers no longer work on single solutions, but rather on processes, which have to be made explicit in order to be encoded. The designer’s creativity and imagination are not restricted by indirect manipulations, or by the particular information imposed by univocal descriptions of models. The design process changes with the cognitive level.

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Patrimoine

Patrimoine

Résumé :

Utilisation d'un moteur 3D temps réel pour la visualisation de plans-reliefs datant du 19ème siècle.
Les plans-reliefs de la collection du musée du même nom décrivent non seulement la ville mais également la campagne alentour. La plupart d'entre eux sont stockés dans des containers sans accès possible. Des modèles virtuels accessibles sur internet permettront de diffuser ces précieuses sources d'informations au grand public. Ce papier présente l'application que nous avons développée pour la visualisation d'une partie du plan-relief de Toul et s'inscrit dans de cadre de recherches expérimentales sur l'établissement d'un processus valide depuis les relevés laser jusqu'à la navigation temps-réel dans le modèle virtuel des plans-reliefs. Bien que Unity soit un moteur 3D temps-réel pour la réalisation de jeux vidéo, nous justifions ce choix et expliquons comment l'API est appropriée à nos besoins. Nous développons les parties suivantes : - le terrain a été relevé par laser et a dû être optimisé et traité pour la visualisation, - pour les bâtiments, nous avons développé des procédures pour le partage de textures lors de l'importation des différents îlots, - en ce qui concerne la végétation, le challenge était de créer de nouveaux types qui ressemblent à la végétation non réaliste des plans-reliefs. Nous avons développé un outil pour planter la végétation sur le terrain à des positions précises. Nous présentons les résultats obtenus et extrapolons le processus au plan-relief dans son intégrité, qui sera 20 fois plus conséquent en taille que la partie effectuée. Le processus a été établi en gardant toujours à l'esprit que c'est la totalité qui devra être mise en ligne : environ 4000 bâtiments et plus de 870 000 pieds de vigne sur un terrain étendu.

Résumé :

Particularités de la modélisation numérique de maquette réduite de ville.
Dans cet article est présentée une nouvelle méthode pour la reconstruction virtuelle de maquettes anciennes. Ce patrimoine est unique du fait du rapport entre une échelle petite et d'un niveau de détail très élevé. De plus, les aléas du temps n'ont pas épargné les matériaux fragiles (le bois, le papier ou la soie par exemple) qui composent ces objets. Notre méthode a d'abord été testée sur une partie du plan-relief de Toul (France) qui représente à la fois des parties urbanisées du la ville mais aussi sa campagne environnante. Le modèle 3D final doit être léger mais fiable étant donné qu'une de ses applications est destinée à être sur le Web. À partir des squelettes de toitures qui ont été extraits manuellement de photographies grâce à Photomodeler, un logiciel de photogrammétrie, il est possible de reconstruire automatiquement chacun des bâtiments présents sur la maquette. Des ajustements automatiques et manuels permettent enfin de corriger les erreurs de reconstruction ou d'ajouter des objets paramétriques tels que de la végétation, des ouvertures, des cheminées, des bandeaux, etc.

Résumé :

Parcours stratégiques et carte mémoire : exploration d'un bâtiment et acquisition de connaissance.
Dans le cadre de la restauration archéologique et architecturale, nous proposons un mode de navigation 3D exploitant des parcours topographiques et cognitifs. Pendant l'exploration du modèle 3D, l'apprenant peut créer sa propre carte mémoire favorisant ainsi l'appropriation et l'acquisition de connaissances. Dans cet article, nous mettons en avant le rapport existant entre les activités d'exploration et de création de connaissance. La grande pyramide de Gizeh a servi de support à ce travail.

USE OF A REAL TIME 3D ENGINE FOR THE VISUALIZATION OF A TOWN SCALE MODEL DATING FROM THE 19TH CENTURY.

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Keywords: architectural heritage, laser scanning, game engine, town scale model

Abstract:

In this paper we present a research related to the virtualization of an old town scale model. This is an experimental work that mainly focuses in establishing a valid workflow from data remote sensing to the real-time on-line walkthrough in the 3D model.

The real scale model encompasses the town itself and the surrounding countryside. Because the scale model is kept safe in containers, nobody has access to this information. Providing an on-line virtual model will unveil both the scale model and its attached information to the general public. In this paper we present the application we have developed for the visualization of the virtual model, using a game engine. After an introduction, each of the following topics will be developed:

Choice of Unity software: although Unity is a real time 3D engine devoted to video game development, we justify our choice to develop in this environment and explain how its API is appropriate to achieve our goals. Terrain: scanned with a hand-held laser scanner, we focus on how we have overcome some difficulties to optimize the terrain management. Buildings: when some geometry is imported in Unity, new textures are created. We have developed a modeling environment so that all the buildings easily share a set of common textures. Vegetation: the challenge was to create new kinds of vegetation that look like the ones on the scale model, that's-to-say not so realistic. We also have developed a tool to "plant" vegetation on the terrain at accurate locations.

Results and future work: we present result analysis and extrapolation of the workflow to the entire scale model that is twenty times greater in size than the part we have modeled. The workflow has been set keeping in mind that the visualization of the whole scale model on the web will be a challenge: 4000 buildings and more than 870 000 vines on a large terrain.

1. INTRODUCTION

Scale models of towns were realised and used in the past mostly for studying military strategies. It was almost the only way for the authorities to have a better understanding of the local peculiarities of the topography, urban specificities and to define attack and siege tactics. They are now museum items and can be seen as a quite accurate depiction of cities as they were at that time, more understandable by the general public than plans, paintings or engraving. Comparing cities then and now, adding information to landscape and buildings by means of virtual reconstructions of such scale models is a convenient way to widely spread this cultural heritage knowledge side.

2. RELATED WORKS

Several works that undertook the modeling of scale models are well known. The modeling of Prague scale model by Antonín Langweil in 1826-1837 is one of these projects [1] [2]. It involved a large team. The relatively small size of parts eased the digitizing (1.6 x 1m for the biggest at a scale of 1/480). It is in much better condition than our model of the city of Toul (France) but the building textures contained thin structures of drawing in Indian ink making textures and their digitalization more delicate than ours.

In the 3D modeling of Beijing city scale model [3], the authors used stereo image pairs of the object to enhance the quality of edges of the scanned model. The point clouds are improved but no 3D geometric modeling is made and no semantic is given to the model. In our project each building needs to be semantically identified for the ultimate web application.

In the 3D modeling of Rome scale model [4] [5], models of complex buildings are manually created [6] and the others are computed with the help of procedural and parametric modeling techniques [7] [8].

Among these projects, only the Prague application is completed, others are still in progress. Prague visualization is performed via a CD-Rom so there is no real-time via the web. For the Rome project, the team will have to handle large databases. Virtools has been used to realize some tests on-line

Since a few years, numerous works have explored the use of game engines for interactive visits of 3D architectures with semantics [9], terrain design, and collaborative design. In [10], the didactic potentials of 3D interactive exploration were particularly emphasized and a learning system proposed.

3. PROJECT DESCRIPTION

The Museum of Plans-Reliefs located at Les Invalides in Paris and the SRI (regional centre for cultural heritage inventory) of the Lorraine region commissioned us the creation of a virtual remote accessed 3D object of a physical scale model dating from the 19th century: the scale model of the town of Toul in France (see Figure 1). Its overall surface is about 39 m^2 and it is composed of 20 parts (called tables). The biggest table contains the town (2.31m x 2.23m). The other tables contain hamlets and countryside. Among the 111 existing scale models, only 28 of them have been laser-cleaned and restored; they are exhibited at the museum in air-conditioned glass cases under specific lighting conditions. Unfortunately the one of Toul is kept in chests, consequently nobody has access to it. Art and architectural historians cannot access to all the precious information contained in such a model. So the aim of the project is first to give everyone the possibility to view a digital facsimile of the real scale model, it would also provide access to numerous detailed information such as plans, elevations, photos, texts, and so on.

This virtual model has to be accessible via the Internet by the largest public, allowing the end user to access parts usually invisible and offering an interface tool for documentation retrieval, regularly enriched and updated.

Several kinds of difficulties appeared:

Difficulties due to smallness: the scale model is at the scale of 1/600: such a small size is not compatible with accuracy, especially when dealing with architectural models. Buildings are a few centimeters high and openings are generally about one millimeter wide. The narrowness of the streets and the density of urban blocks made difficult the visual approach to some parts to take pictures or for the laser scanning.

Even at the smallest laser scanning resolution, hard edges were rounded out in the resulting 3D mesh. Beside the hand-held laser scanning, pictures were taken in high view angle (touching or getting close to the scale model was forbidden), making difficult the positioning and sizing appreciation of the openings.

Difficulties due to inconsistencies:

The physical scale model is neither a perfect depiction of the 2D elevations and plans that were first drawn prior to create it, nor a correct representation of the reality as it was when it was built. Numerous architectural inconsistencies occurred during the physical creation of the scale model in 1840. Errors also come from the methods used during the survey: at that time, lengths were measured in the real city using feet as unity of measure and the heights were estimated following a simple and visual proportion principle. So elevations were visually drafted: openings weren’t measured but only proportionally sketched. Also during the realization of the scale model, manual cuttings of the pieces (lime-tree wood, paper) used for the houses contributed to multiply the inaccuracies (that's why walking in the virtual 3D model as a pedestrian is not desirable).

Difficulties due to the poor condition of the model:

Lots of paper pieces, representing house fronts, are unstuck or torn, notably modifying the buildings geometry and the opening shapes. Any mistake or imprecision becomes instantly obvious when one wanders in the virtual 3D model without scale and especially if one walks on the ground as a human being. The change of scale increases the architectural incoherencies: one millimeter error on the scale model corresponds to 60 centimeters in reality. Lighting conditions and restrictions (usually no more than 50 lux allowed) and dust deposit made the pictures difficult to take and tedious for photo-modeling use.

For all these reasons, both 3D and 2D data had to be carefully checked to determine if they were reliable. The final result of this experimental modeling was to produce a reconstructed model of the scale model, not as close to the real thing as possible, but sufficiently accurate to depict it and interactive enough for a real-time Web access.

Ergo this is not only an archiving process (laser scanned data has been stored separately) but also a proof of concept to set up a valid workflow in case of a complete modeling of the whole scale model (Figure 1) or of other scale models of the collection as well.

For more information about the creation of the 3D model you are invited to read [11] [12].

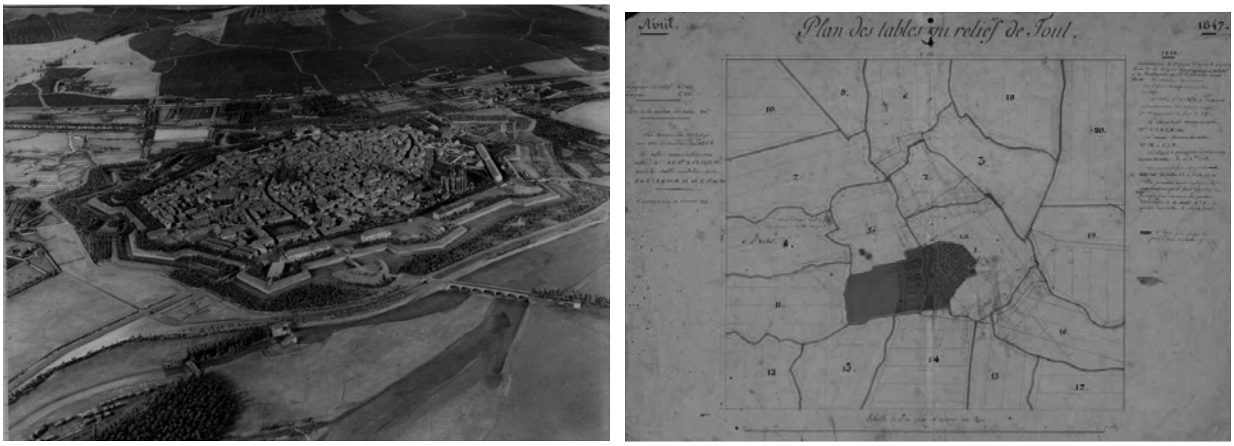

Figure 1: a) Picture of the physical scale model of Toul. b) Map of the tables of the scale model, filled areas are those modeled.

4. UNITY SOFTWARE

Unity, by Unity Technologies [13], is a real time 3D engine originally and specifically devoted to video game development (online or standalone cross-platform games). Among other advantages, it can handle huge databases, stream geometric asset bundles, pre-calculate lighting or perform real-time lighting, provide interactions and animations capabilities, attach behavior scripts to objects, while preserving a fluent visualization of the final product.

Unity applications can be played on the web via a cross-browser free plug-in on PC-Mac-Unix environments (as well as iOs, Android, Wii and Xbox consoles), so there is no need to write our own visualization software.

The development environment abstracts away the majority of platform differences, as it uses both Javascript and C Sharp coding languages. Building the final executable for any Web browser does not make any difference in the coding phase.

Our project needs such characteristics: the scale model is composed of more than 38000 pieces of vegetation, near 1000 buildings, which represents the twentieth of the whole model. Along with Unity's programming environment, it turned out to be the most convenient and efficient software.

Having written scripts helped us to simplify the handling of the project, facilitated the gathering of external data from various sources, and optimized the size of the database as well as the final application executable file and finally automated the modeling as much as possible.

5. THE TERRAIN

Unity terrain engine has an editor to create realistic terrains with sculpting tools and provides many ways to texture and populate the ground base of the scene, but these are mostly dedicated to natural landscapes. As we had to deal with a very particular and partially urban environment (many streets and houses, fortifications, rivers, bridges…), these built-in tools appeared at a first glance to be quite inaccurate and almost useless.

The global mesh acquired with a HandyScan laser scanner [14] was then cleared of all vegetation and man-made objects, and holes were filled. A script was developed to generate a precise height map of the landscape layer, based on this simplified mesh. Even at the highest resolution available, this Unity terrain turned out to be lacking of precision, but was usable for planting vegetation (see paragraph 7). Moreover, from a technical point of view, a first trial to import the overall terrain as a so-called "Unity mesh asset" quickly showed some issues: a 3D mesh cannot contain more than 65000 polygons and texture mapping is nearly unmanageable (no UV mapping possible), among others. So the entire mesh had to be split in two parts (one for each table), only slightly increasing rendering time and not noticeably slowing down the visualization. UV mapping texturing can hardly be completed within Unity, so the texturing of these two meshes was realized in the Maya environment, thanks to high-resolution top-down straighten photographs of the scale model, seamlessly mapped on each part. That is why our terrain consists of two layers: an invisible native Unity terrain (used for vegetation) placed just below the cleaned textured mesh parts. For the countryside table part, where accuracy is less important, the terrain model is a simplification of the digitalized mesh by means of a vertex-clustering process. For the town table, streets were also replaced by a decimation of the original mesh on their area.

6. THE BUILDINGS

The town table mainly contains the fortifications surrounding the city, streets and about thousand houses. In order to reduce the number of polygons and sharpen the ramparts walls, a model of the fortifications was redesigned on top of the relevant laser data, with Maya software.

6.1. Blocks and houses geometry

For each city block and house, a semi-automatic modeling process combining several technologies was developed: roofs edges retrieval, parallelism and planarity corrections, overhangs calculations, base walls footprints calculations, all this leading to a set of parameters allowing the creation of the main geometry of each building [12]. Additional elements (chimneys, lonely walls…) are then added thanks to a dedicated utility we developed, combining the parametric model, photos, and a library of architectural objects and laser data to locate chimneys. The openings are a particular case: on one hand they cannot be retrieved from the laser data (they are made of pieces of paper glued on the façade) and it was sometimes impossible to get a picture of each façade due to the narrowness of streets and inner courts; on the other hand, the final model cannot contain one texture per façade (of the wall and openings). When it was impossible to get a picture of some narrow or inaccessible parts, we used the paper drawings of the city blocks to add 3D openings. At the end of the modeling process, each house is composed of a mesh for the walls, a mesh for the roof slopes, one or more meshes for the openings, one or more meshes for the chimneys. For Unity, we combined all these elements in a single mesh to make it a unique clickable object. We worked block by block, importing each block into Unity the usual way. A script is then run that removes duplicated materials and replaces them by shared materials, adds a collider to each house, assigns each house a unique identifier, and finally attaches a behavior script to its mesh renderer so it becomes highlight-able and clickable. Dwarf walls, fences, entrances gates and railings were created with the same method than the trees rows (see paragraph 7.2). Rare and specific elements were manually added with Maya: several parapet walls and bench terraces.

6.2. Textures

When some geometry is imported into Unity, no matter the source format, new shaders, materials and textures are created from the input file. Since each house, in the parametric modeling stage is output as a particular mesh with its own shaders, an additional texturing step is required if one wants this house to share its textures with all the other houses. That's why we developed a script so that all the buildings share a unique set of common textures, assigned within the parametric modeler by object type: walls, roofs, chimneys… No re-texturing of individual houses assets was required within Unity. This simplifies the transfer of the geometry, allows a faster on-line loading time, decreases file sizes and offers fluid real-time display: textures amount plays a great role in minimizing draw-calls to the graphic card. Since photorealism was not really the essential concern, we used basic diffuse shaders (no effects, no normal mapping, etc), just flat diffuse mixed texture maps to fake torn and dusty paper. If needed in the future, modifying the overall aspect of the model all over the project would require a modification of only a few parameters of these shaders and would be very quick. The real terrain on the scale model is covered with glued sand and sprayed silk bits in the crops areas and drawn paper in the streets and courtyards. The 3D meshes of the terrain were mainly textured using on top-down views of the scale model for the countryside parts.

6.3. Links and names

Besides geometry, data must be attached to any house or monument in the model, especially a link to additional information sources such as web pages. Each building, street, road or monument can potentially direct the user to a web page that contains more information about it, through a link.

The final virtual model is hosted on a French Ministry of Culture server, among the various databases related to cultural heritage. These databases may change over time, information is added on a regular basis, so web pages and URLs may vary. Since a link to such a web page can vary over time, no link data were hard-coded in the model itself, but each house was given a unique code that is hold in an external file, as an array of keys (houses codes), houses names, and values (corresponding URLs). The code is a text string output by the automatic process that creates the building geometry. The house name and the URL are entered manually. The house name appears at the bottom of the web player window when the mouse is over a building. When the user hovers a house, both the code and the corresponding name are retrieved (for instance "BLOCK 41 – HOUSE 16", "Apothecary house"), this name pops-up in the interface, and the corresponding URL is called and sent to the browser if the user clicks on it. This external file is a simple yet effective way to avoid compilation of the application each time a minor modification must be done.

7. THE VEGETATION

Seen the significant number of trees, three concerns had to be addressed: low-poly modeling, accurate and easy location of vegetation, fluent and correct display.

7.1 Low poly modelling

Unity comes with various realistic vegetation types and species (mainly trees and shrubs) in a built-in library, as well as a procedural tree creator (such objects are called 'prefabs'). Using trees in Unity is obviously intended for creating a realistic vegetal environment. However on the scale model, vegetation does not look realistic: trees and shrubs are made of twisted copper wire, hacked silk and small silk twisted ribbons (Figure 2). The challenge was to create other kinds of vegetation that look like the ones on the scale model. Six main tree species, two bush types and a wine stock were identified. Each of these comes in a variety of three subtypes. The Unity tree engine was used to create each of the types, with a low-poly modeling in mind. Trunk texture is a repetitive wire-looking sample, leave textures were captured and outlined from macro pictures of the real scale model. The hierarchy was kept as simple as possible, just adding some branches to the trunk and a few leave groups.

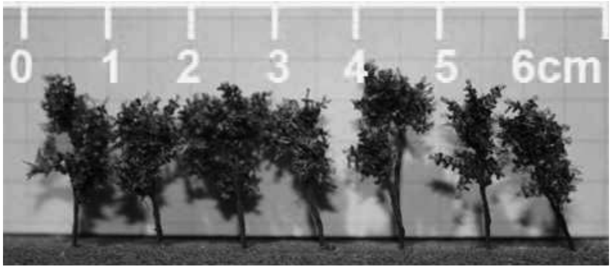

Figure 2: Trees on the scale model are made of twisted wire and silk.

7.2 Positioning the vegetation

A second problem was to accurately locate a bunch of vegetation pieces. The laser scanner data being awkward for that task, we developed a semi-automatic process that is able to generate or update all the vegetation of the terrain in a matter of seconds. First we used top-down photographs to manually digitalize lonely trees as points, ranks of trees as lines, and forests or groves as polygons, indicating the species and density to each geometric object as parameters. The resulting 2D data was then processed by a script to set the 3D coordinates of each trunk base, thanks to a top-down ray-cast method that intersect the terrain. Moreover, using this process overcame limitations of Unity terrain engine: one cannot accurately locate trees on a terrain with the native brush tools, which more or less randomly plants vegetation, and one cannot plant trees on other matter than a height map terrain. That's why our terrain mesh has a second invisible terrain underneath. This way, the tree prefabs can be easily modified and the whole vegetation could be instantaneously removed and updated if needed.

7.3 Use of billboards

A third problem was to preserve a fluid visualization of thousands of trees. To a certain extent, Unity comes to the rescue: one great feature is its ability to handle and display a hatful amount of vegetation pieces and to achieve that, the rendering engine is able to create on-the-fly a billboard for each vegetation 3D mesh. Terrain settings include thresholds to switch from 3D mesh representation to 2D billboards, transition distance, among others. Since 3D vegetation mesh instances are limited to 500, billboards are extensively used in our case because this parameter highest value is always exceeded. Two issues arose: first Unity produces a visible pop when switching from mesh to billboard representation, and secondly, the higher the viewpoint, the more the billboards seem to sink in the ground (because they are designed to be seen from a pedestrian viewpoint). As the number of vegetation elements is important (more than 38000) the distance threshold for swapping the representation is quite close to the camera. The changeover would then be seen if no particular attention was paid to the overall shape of each tree type. Finally, to avoid the 'sinking effect', a script was developed to raise the height map terrain as the camera viewpoint gets more and more top-down.

8. USER INTERFACE

8.1 User interface

Unity provides classes in a customizable interface to the GUI. The default skin has been used to select options and items from a pull-down menu: the user can examine the model in windowed or full-screen mode, choose a guided tour or freely inspect the model, display a map of the city or select a particular block to examine. Menu, options and map display are adapted automatically to any screen resolution both in the standalone application and in the web player. They were designed to take as less place as possible on the user screen.

8.2 Predefined walk-through

We have decided that the user would not be able to visit the 3D model walking in the streets or in the crops (Figure 3): having a pedestrian viewpoint doesn't make sense and could even give him a false interpretation of the scale model reproduction intents: the real scale model is always seen from a distance, say one half-meter. From that distance, the size of the openings for instance is very small. We consider that the virtual model must be seen at about the same scale to avoid misinterpretations of its accuracy. That's why the walk-through are run from above. They follow major urban features (streets, ramparts, monuments). What is important for us is the global comprehension of the scale model at the urban scale, not the understanding of each constitutive object. Programmatically speaking, creating a new walk-through and its camera path just consists of digitizing waypoints on the map of the city and give that path a name. A script integrates it in the menu and if selected by the user, it smoothes the camera movement from a waypoint to the next. Two of such paths have been created to illustrate the thematic visits that will be set up on the complete model: ramparts and commercial street.

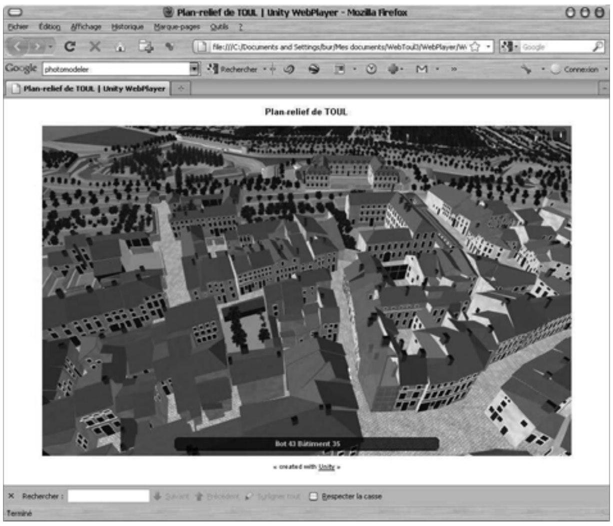

Figure 3: The virtual model displayed in a web browser.

8.3 Map locator

Each city block was given a number on the map. An option of the menu displays the original map of the city and a layout of clickable buttons to quickly move the camera near the corresponding city block. When the user clicks on a numbered button, a script searches in the assets which city block has such a number in its name, computes its bounding box and locates the camera with an offset so that the user sees the block full screen with the same orientation than the 2D map.

Thus, adding more city blocks doesn't need anything else than this generic locator.

9. RESULTS AND FUTURE WORK

Analyzing the process we have defined gives us some clues to further enhance the workflow when the whole scale model will be digitalized, having in mind that a completely automatic reconstruction is impossible, but diminishing phases where a human action is mandatory is envisioned.

An automatic segmentation of the point clouds (beyond the scope of this paper) as well as an image-based automatic positioning of the openings (currently under development). Keeping the data that are loaded in the web player as small in size as possible will induce streaming the 3D model as the user will visit it.

We shall probably define new 'game objects' structures to encapsulate existing ones ('tables', city, countryside), add some semantics to our objects (land and house use, still existing, construction date …) to be able to manage walk-through and thematic displays.

Other applications may arise: the scale model could be visualized on an interactive terminal in the museum, and a didactic game can be developed, featuring the principles we have developed in [10]. More visual information can be added to the model, for instance to compare the actual city to the former one, or to highlight elements thematically: agricultural areas and their types, particular topographic elements, use of buildings, military facilities and so on. Figure 5 below presents a comparison between Prague and Toul projects. It also presents an estimation for the entire scale model of Toul. The challenge will be to handle such a big model through the web.

	Physical model					
	Date	Scale	Surface area m²	Tables number	Material	Condition
Toul (actual)	1846–1861	600	1.88	2	wood, paper	poor
Toul (entire)			38.82	20		
Prague	1826–1837	480	20	52	wood, paper	good
	Digital model					
	Date	Houses	Openings	slopes	Chimneys	Vegetation
Toul (actual)	2009–2010	974	4788	2300	577	38 000
Toul (entire)	2012	3742	20 000 est.	9000 est.	2400 est.	760 000 est.
Prague	2006–2008	2500		13 400	9100	5400
	Staff	Working hours	Photos	Laser data	Triangles	Web player tris
Toul (actual)	6	5 000	2 000	0.5 Tb	11 000 000	300 000
Toul (entire)	6	30 000 est.	20 000 est.	10 Tb est.	200 000 000 est.	6 000 000 est.
Prague	62 – 110	18 000	244 000	T8 Tb		

Figure 5: Comparison between Toul and Prague projects, estimated data for the entire project.

10. CONCLUSION

In this paper we have presented an overview of the techniques we have used to reconstruct a virtual model of an old town scale model, from the initial laser scanning step to the final on-line application [15]. We have justified our choices to develop the product within the Unity environment, listed the difficulties we have encountered and explained how we overcame them.

The workflow we have defined, being perfectible, has been set up in a way it will be easily used to reconstruct town scale models that are twenty times greater than the part yet modeled, in a shorter period of time.

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Modelling specificities of a physical town scale model.

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Abstract

In this paper, we present a new method for the 3D reconstruction of town scale models. They are special objects because of the very small size of the buildings and of the other details in comparison to their corresponding one-by-one scale objects. Furthermore time hasn't spared the delicate materials like wood, paper or silk covering our scale model. Our method was first tested on the scale model of Toul (France) which contains both built-up and countryside environments. The virtual 3D model has to be light but reliable because one of the applications will be on the web. Thanks to the skeletons of the roofs manually extracted from the pictures with Photomodeler, we automatically create buildings. Automatic and manual adjustments allow us to correct geometrical deformities and to add parametrical objects like vegetation, openings, chimneys, belt courses, etc.

Keywords: 3D modelling, web application, cultural heritage, photogrammetry, lasergrammetry, scale model.

1 Introduction

To preserve and promote our cultural heritage, computer digitization has been widely used for years: scientific and architectural studies for surveying the evolution of the building deformations, virtual visits for a better understanding of a monument or a city, illumination simulation projects, better access to delicate heritage objects for researchers as well as for the general public.

Even though sensors and techniques are widespread, the variety of artifacts is so huge that some objects may not be digitized thanks to these well-tried methods. Contrary to statues, buildings or archaeological sites, less work has been conducted in digitization of scale models. The size and scale are components to be taken into account when scale models are the aim of a project.

The Museum of Plans-Reliefs at Les Invalides in Paris and the SRI (historical research center) of Lorraine have given us the task of creating a virtual 3D object of a physical scale model dating from the 19^{th} century: the scale model of the town of Toul in France (see Figure 1).

There are about one hundred scale models of French towns, all at the scale of 1:600. They were made from the 17^{th} to the 19^{th} century by the army to visualize fortification projects or to elaborate war strategies. Built in the 1840s and modified in the 1860s, the Toul model was made a few years before the end of the fortification systems. Its size is about 39 m2 and it is composed of 20 pieces (called tables). The biggest contains the town (2.31m x 2.23m). The other tables contain hamlets and countryside.

For 2010, we were asked to model a part of the town table (see Figure 2) and a countryside table (1.50m x 2.50m) (see Figure 3). This first test must enable us to elaborate an “as automatic as possible” method and determine if it is conceivable to digitize the other tables of the scale model of Toul and also other scale models of the collection.

The need to digitize the scale model of Toul is multiple. By creating a 3D model, we preserve a witness of the architectural and urbanism evolution. As we will see in part 3, the model of Toul is in a bad state due to its age and to the conditions of its conservation. There is also the will to provide a greater access to this delicate model for the general public and for historical researchers because most of the scale models are stocked in boxes where nobody can see them. Only 26 are currently exhibited at Les Invalides Museum behind glass to avoid dust deposit.

Interactive terminals for the museum and web applications are the best media to solve the lack of visibility of the smallest town parts of the scale models. They will also allow navigation into the virtual model which means a greater access to further information via hyperlinks.

Apart from the scale model, we also have at our disposal 2D plans (roof plans and elevations plans that have been used by the original model makers). Unfortunately, we were not able to use this precious information because of the inconsistencies between them and the scale model. However, these plans helped us to get our bearings in the great amount of buildings (more than 4 000 in the town).

The project of digitization of the scale model of Toul is at the mid-point of two research fields: photogrammetry and lasergrammetry on the one hand and 3D parametric modelling of architectural elements on the other hand. Complex architectural elements are still impossible to obtain without human handling but it is likely that some steps can be accomplished automatically with a minimal user help.

In this paper, we present the project starting from the 3D modelling of the buildings and vegetation to the web application we have developed. After a presentation of related works (part 2), part 3 explains the specificity of a scale model compared to a town. Then the method we have conceived and developed for an "as automatic as possible" reconstruction of the building is explained in part 4; this part has been explained in detail in (Chevrier, 2010). Part 5 deals with the modelling of vegetation. The web application is exposed in part 6. Finally, we conclude and present future work in part 7.

Figure 1: Picture of the scale model of Toul

Figure 2: Picture of the city table of the scale model of Toul (France).

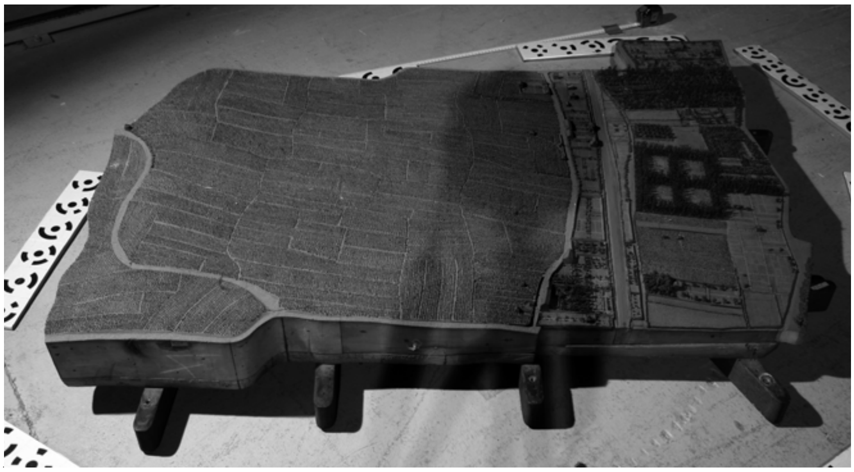


Figure 3: Countryside table (1.5 x 2.5m). Vegetation is widespread and of various kinds. The biggest part is planted with vine stocks.

2 Related works

Methods for the creation of digital models from physical scale models can be classified in two kinds: manual accurate modelling with CAD tools and many people or plausible automatic modelling with procedural methods. We haven't yet found any automatic and accurate modelling of town scale models.

The Langweil model of Prague was made in 1827 (http://www.langweil.cz/index_en.php). It is half as big as the scale model of Toul and its 52 tables (160 x 100 cm for the biggest) allow a better access to the different parts of the model. The scale is bigger: 1:480 and it is also in much better shape. Textures are more elaborate but the volumetry is basic with paint windows for instance. More than two hundred people skilled in robotics, programming, modelling and photographing were involved and a partnership with Autodesk was made to take advantage of their experience. A special robot was created to photograph each of the 52 parts of the model thanks to cameras containing macro-optics, highly precise CCD sensor, etc. However the 3D modelling of the buildings was realized manually. ImageModeler software was modified to meet the issues of the building reconstructions whereas photogrammetric treatments of points cloud from 3D scanners ensure the creation of the digital terrain model (DTM) (Sedlacek, 2009). Two kinds of applications were carried out with the resulting model. The first one allows scholars to examine the digitized model, without having to go to museums, reducing the risks of spoiling. The second kind of applications is CDs designed for the public with interactive virtual guides or adventure games for children.

Carried out by several university laboratories, the Rome reborn project aims at illustrating the urban development of ancient Rome from 1000 BC to 500 AD thanks to the Plastico di Roma antica scale model. Because of the size of the model (280m2), the researchers have chosen to digitize it by means of two lasers: a 3D laser radar (time of flight laser) because of the large dimensions of the physical model and a triangulation laser for the digitization of detailed parts. (Guidi, 2005; Fuchs, 2006). For the 5% of well documented buildings (Circus Maximus, Colosseum, etc.), the 3D reconstruction is made thanks to Autodesk 3DS or Multigen Creator. What remains, about 10 000 buildings, is modelled with CityEngine, a procedural tool that uses the volumetric data from the 3D scanner to create credible buildings but not necessarily correct (Dylla, 2009). The model is thus a representation of the state of our knowledge that can be easily updated to reflect new discoveries. The medium used to diffuse this model is the popular Google Earth application.

Few others projects were carried out. For instance, there is the project of 3D reconstruction of the scale model of Beijing (Zhu, 2009). The whole model was made in the 1950s and assembled using 94 parts. The 1:1000 model covers an area of 75 m2. The digitization is carried out thanks to structured light photogrammetry and extraction algorithms. Few tests were done and no application is known. See (Chevrier, 2010) for related work in photogrammetry and lasergrammetry methods.

3 Specificities of a scale model compared to a town

The aim of the project is to get an “as accurate as possible” virtual 3D model of the scale model of Toul in France. The scale model is made of delicate material like wood, paper, and silk. Compared to a 3D modelling of a real size town, the plan-relief has its own constraints due to its scale, size and age:

- Due to the very small scale of the physical model (1:600), the buildings are a few centimetres high, openings are often one millimetre wide, streets are about 1 to 2 cm wide with some alleys less that 5 mm wide. The physical scale model is not a perfect representation of the reality. Such a small size is not compatible with accuracy. Numerous architectural inconsistencies were made during the physical creation of the scale model in 1840. Any mistake or imprecision is instantly obvious when you are in the virtual 3D model without scale.

- There is just the essential on the scale model: no perturbing objects in the streets (trees, urban furniture).

- Digitization has to be carried out without contact, purely on optical principles using non-contact, non-destructive sensors.

- Because of the density, some areas of the model are not easily accessible, many houses cannot be well documented.

- Moving the model without a skilled team to access some areas is impossible because of the size, the weight and the fragility of the model.

- The scale model is in a bad state: papers are unstuck or missing, a lot of dust is on the model, and slopes are skew surfaces (see Figure 4).

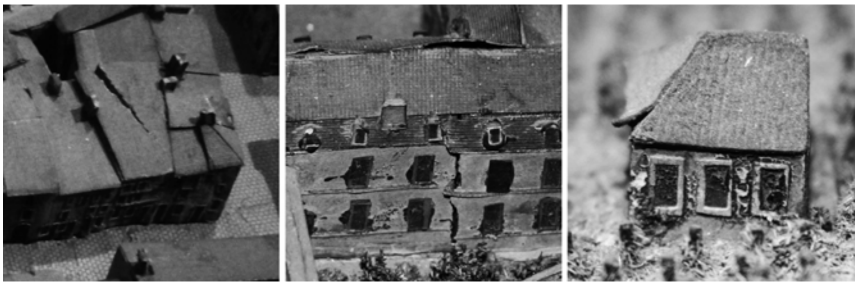


Figure 4: damage is widespread: unstuck papers, lots of dust, skew surfaces due to deformation.

4 The method

Because of the specificities of the project, the range of tools suitable for digitization becomes restricted. Moreover, it is necessary to combine several technologies like image-based processes (Photomodeler http://www.photomodeler.com) and range-based modelling (Geomagic http://www.geomagic.com) to achieve the digitization of the scale model. The key to this work is to merge these technologies where they are best suited. Figure 5 shows the principles of the method.

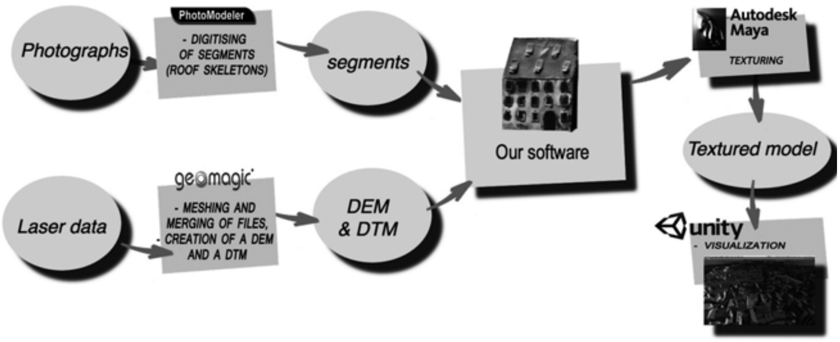


Figure 5: Principles of the method

The scanned ground geometry is treated with Geomagic to create the DTM (Digital Terrain model) that will be used as the ground model for the countryside.

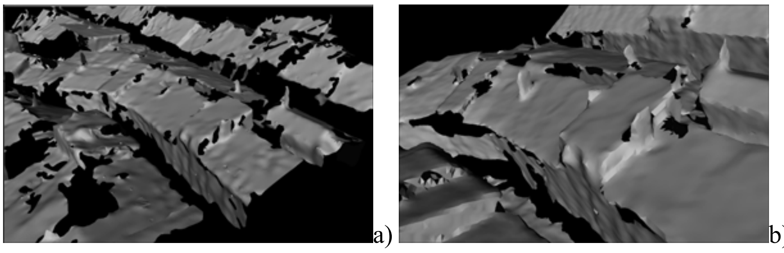
PhotoModeler, a photogrammetric software, lets us recover the roof edges of the buildings and low walls. They are automatically reconstructed taking into account several parameters and constraints like the roof slope planarity.

Maya software (http://usa.autodesk.com) is used to texture the model and Unity software (http://unity3D.com) is used to create the application.

5 3D modelling of the terrain

We were not allowed to touch the model. After much discussion we were authorized to lay several sewing threads in surrounding streets. In the first experimentation, the use of the Handyscan scanner (http://www.creaform3d.com/en/default.aspx) allowed us to have a roughly 3D model of the city where houses looked like heaps of sand (resolution of 2 mm). To obtain usable laser point clouds, we had to increase the precision of the tool which delayed the operation (half a day for a 30cm x 30cm box) but makes easier the positioning of the 3D buildings on the point cloud. Nevertheless, we encountered difficulties in accessing the inner blocks. Furthermore, the scale model of the town part is just one big object (2.31 x 2.23m).

Several tries have were made (see Figure 6) with various laser precisions: 0.3mm and 0.5mm. At 0.3 mm, results are accurate but the time taken to scan is too long. We could not spend two months on the scan. A 0.5 mm precision turned out to be a good compromise between quality and the time spent scanning: 6 days for the town part.



a) b)

Figure 6: Scanned parts realized with a precision of 0.3mm (part a) and of 0.5mm (part b). A resolution of 0.5 mm is a good compromise between time spent and quality.

From the DEM (Digital Elevation Model) we created the DTM with Geomagic (http://www.geomagic.com): buildings and vegetation were removed, holes were filled. The DTM was used as a support for the setting up of buildings and vegetation. The country part of the DTM was textured and used as the virtual terrain for the 3D visualization.

For the city part, a Delaunay triangulation between the houses' ground polygons was then carried out thanks to Triangle software (http://www.cs.cmu.edu/~quake/triangle.html) in order to replace the DTM corresponding to the roads with a lighter model so that the web navigation remains fluid.

6 3D modelling of the buildings

Three main steps must be completed to obtain the 3D model of the buildings. PhotoModeler, a photogrammetric software, lets us recover buildings' roof edges and low walls (part 6.1). Then automatic corrections of the segments are applied and the buildings are modelled (part 6.2). Finally, to have an accurate model, many objects are added to the buildings like chimneys and openings (part 6.3).

6.1 Segments created with PhotoModeler

As mentioned before, the size of the town parts and dust deposit are constraints that extend the time spent in taking photos. The rear of the buildings can be very dense especially in the centre of the model where the city blocks are hard to reach. Thus photos do not show every part.

The first step of the method involves the manual digitizing of segments forming the roof skeletons (Figure 7). To create a 3D point, we have to locate it in two photos but there is nothing to prevent the creation of this point on other photo-couples. The treating of these extra segments is a waste of time. Moreover, the geometry created by PhotoModeler has no geometrical properties held by the buildings like parallelism, planarity or horizontality. Like every photogrammetric tool, bad orientations or inaccurate points contribute to a lack of quality but in our case, the model is so damaged that everything is irregular.

We work city block by city block with oblique pictures. The level of accuracy of the photometric data is around seven pixels for all the city-blocks. This high level is due to imprecise points we had to position although they were not seen in any picture or to points in blurred parts of the pictures. This level of accuracy corresponds to approximately half a millimetre.

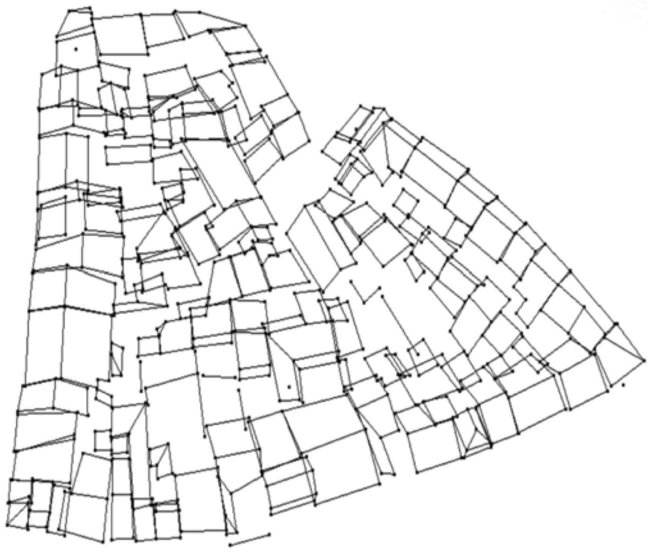


Figure 7: The roof skeletons of a city block before geometrical corrections

6.2 Modelling the roofs and walls

From this point, we use our own software to carry out the following processes. For more detail of this part, see (Chevrier, 2010). The segments of a city block are positioned automatically in the DEM with the help of three selected points in the DTM and the three corresponding points in the PhotoModeler data. This allows us to scale and orientate the segments. Manual refinements are possible if necessary.

Then automatic treatments modify the geometry of the segments to correct parallelism or remove excess points and segments to make up for the PhotoModeler's geometric imprecisions (every face is a skew surface, nothing is parallel and roofs can penetrate each other).

We developed algorithms able to identify every kind of edge and slope of a roof. Thus, roofs are modelled with parameters and constraints like planarity of the roof slopes, horizontality of the ridge. Overhangs are modelled and some values are automatically computed from the relationship between two neighbouring roofs. Finally the walls of the building are created by projection of the roof points on the ground (DTM).

6.3 User interface for the refinement and the adding of openings

Finally, a user interface allows us to modify some parameters, apply constraints or change values. For each edge, we can play with the type of segment and its overhang value. Roof thickness, roof planarity, horizontal roofing, parallel roof edges or ridges are the parameters for roofs. However, we allow the possibility to modify the position of a point in case the constraints fail to treat that point.

At this stage and to complete the model, we can add elements. Some of them are attached to the walls (openings or belt courses) while others are attached to the roof (chimneys or dormer windows). Some problems occur during the sizing of these objects. While the chimneys may be easily located and sized thanks to the superposition of the MNE, the openings are a real issue. They are realised on the physical model with stuck papers, so they do not appear in the laser data. We have to rely on photographs. Because we cannot have orthographic views of the facades, the heights are crushed and openings tend to be shorter than they really are.

The positioning of an opening is automatically made on the chosen facade with the parameter values given by the user. The user estimates the parameter values with the help of the pictures. This step relies on a personal appreciation. Various persons do not produce the same results. This task is time consuming and must be improved and automated in the future.

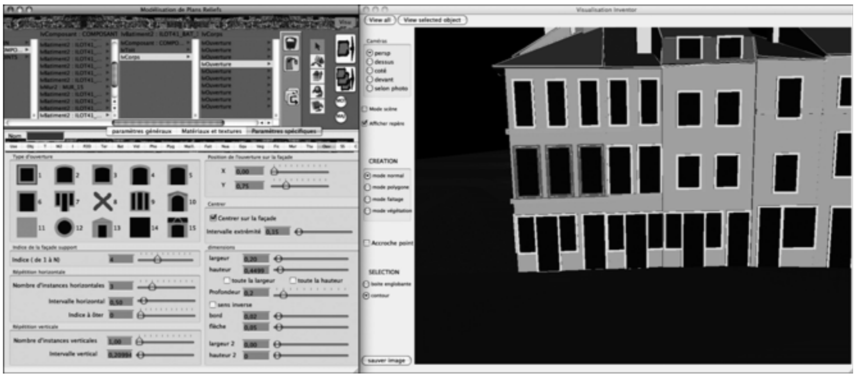


Figure 8: The interface for the positioning and the sizing of the openings.

7 3D modelling of the vegetation

Vegetation on the physical scale model is mainly made of copper wire and pieces of silk. We have identified approximately ten main kinds from salads or cabbages in kitchen gardens to high trees like beech trees in forests. Some written documents tell us what kind of trees was used in some streets or squares and how vegetation was made.

Each kind of vegetation has been modelled directly with Unity sofware. We have developed an application to plant vegetation on the DTM. On the DTM textured with a picture of the table, the user locates some points and indicates which kind of vegetation it is. In our software we only materialized the location and the kind of vegetation with various colours and sizes. It is only in the Unity application that the 3D vegetation models are used.

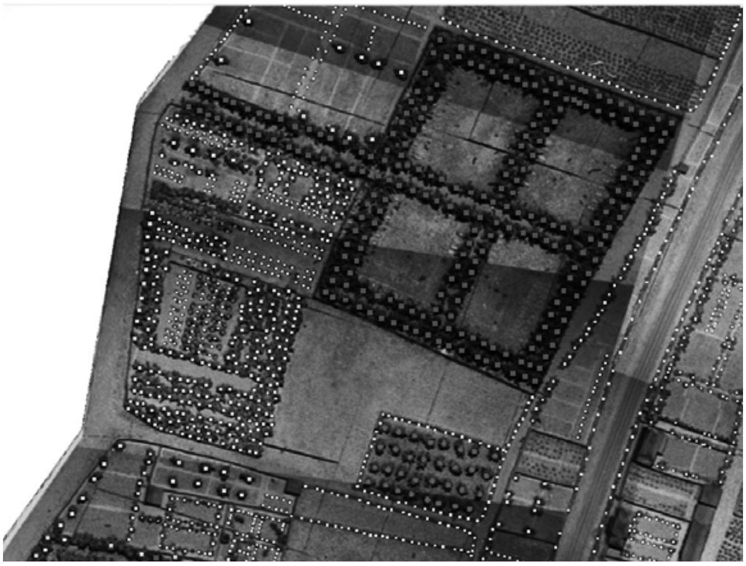


Figure 9: We plant some vegetation on the DTM of the country table.

Figure 10: Simplified representation of vegetation for the creation step.

8 Web application

In order to have a fluent move in a heavy database via the WWW, one must choose a powerful 3D viewer. We have chosen Unity software, which is a game development tool that can be used in the web. It is appropriate to handle heavy 3D models. Our aim is not to create a game but the potentiality of these kinds of software is great. Via the web, a free Unity player is used.

8.1 Unity

Unity has a graphical user interface for the creation and handling of 3D objects. We can also predefine some paths of navigation or leave the user free to navigate by himself in the 3D model. Unity handles the collisions on the contrary of VRML viewers for example. It allows also writing some scripts to create one's own specificities.

About 8400 vegetation objects (without the 30000 vine stocks) are present in the two tables. The number of buildings is close to 900. We estimate the total number of buildings to be up to 4 000 for the entire scale model. It is difficult to assess the total amount of vegetation but we know that there are 871000 vine stocks according to the written documents of that period.

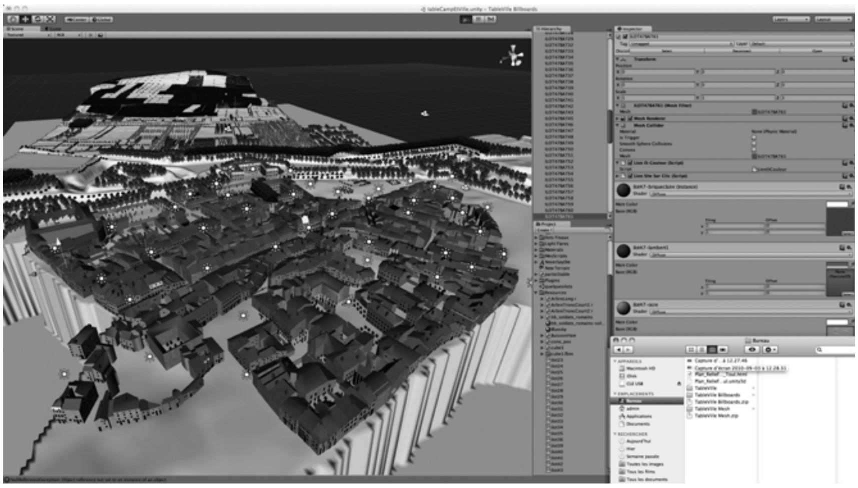


Figure 11: The interface of Unity and the final 3D model for vegetation.

8.2 Navigation and access to other documents

Each building and road can be potentially linked to a web address for more information. To avoid game compilation each time there is a change, we use text files in which is written a correspondence between an element and a web address. When the persons responsible (let's call them the game masters) of the files have a change to make, they only make changes in the files and do not touch the Unity game anymore. The web address for a building gives information on that building or on the city block. It is most of the time a request in a database containing documents (images, pictures, sketches, texts, etc). There is another file for the name that must appear as information when the mouse is over an element. For instance, the building named "BLCOK35HOUSE24", computer name automatically given during the creation process, must display: "Saint-Gengoult Church".

Figure 12: Part of the city. Objects that appear in red when the mouse is over are clickable to access specific information about it.

Figure 13: the country table and its vegetation.

9 Conclusion and future work

In this paper we have exposed the methods and software we have developed for the reconstruction of a scale model of a town made of wood and paper: we automatically create the buildings from segments manually extracted from the pictures. We have also presented the web application we have created to allow researchers and the public to navigate in the model.

One can access the 3D model on: http://www.crai.archi.fr/Toul/modele.html

Till now, only a part of the town has been modelled (approximately 1/14). The data files for that part is 23 Megabytes. Tests made via the web with various connections types and computers were satisfactory. However it will be a challenge to display the 3D virtual model of the entire scale model of Toul on the web.

This project was a one-year contract financed by the French Ministry of Culture. In the future we will try to find financial support to model the other parts of the town and the other countryside tables. We will also work on the textures to improve the shading of the buildings. As far as the automatic process is concerned, several important points could be improved or tested:

- Trying our methods on existing towns (aerial photographs and laser data).

- Improving the step of acquiring the segments of each roof. This step is currently carried out manually with PhotoModeler software. For this we plan to collaborate with researchers in computer vision and photogrammetry.

- Implementing automatic techniques for the positioning of textures and openings.

- Making use of the DTE to adjust the roof geometry with an automatic detection of planes as in (Tarsha-Kurdi, 2007) for example.

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Strategic paths and memory map: Exploring a building and memorizing knowledge

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Abstract. Restoring archaeology and architecture, we propose a 3D navigation mode based on topographic and cognitive paths. During the exploration of a 3D model, the learner can create his own memory map facilitating the appropriation and memorization of knowledge. In this article, we will correlate the exploration and creation activities. The Great Pyramid of Giza is a support to this work.

Keywords: Archaeology and architecture, strategic path, memory map, learning.

1 Introduction

This work deals with archaeological and architectural restoration. The aim is to teach the public by facilitating the appropriation and memorization of new knowledge of cultural heritage. The system presented proposes a 3D navigation mode based on strategic paths dedicated to learning.

In our system, the real-time visit of an archeological site or an architectural monument leads to two activities that the learner performs in parallel:

- the exploration of the 3D model
- the creation of the memory map

These activities belong to a real educational project: the exploration based on clues discovery and riddles resolution incites the learner to participate; the creation helps the learner to organize and visualize information. Both processes allow him to structure and construct knowledge.

During the exploration activity, the learner is guided and motivated in sequenced and superimposed routes, while allowing a lot of freedom. This structure in double layers is composed of the topographical path and the cognitive path. During the creation activity, the learner materializes his mental map. The memory map evolves according to the progress of the learner on these paths.

In this research work, we will correlate the creation of the memory map with the kind of narrative proposed during the exploration. In our study, we will choose the Great Pyramid of Giza in Egypt. With the help of Tristan Truchot, we created a prototype of an extract of the scenario to estimate and experiment our work.

2 Strategic paths

2.1 The topographical path

To be able to structure the movements, we introduce the notion of the topographical path by identifying critical points and secondary points in the path and by putting them in concordance. It is necessary to choose in the studied building the interesting critical points according to the message that we want to communicate to the learner. Each crossing point suggests specific actions that we wish to represent in the topographical path. The crossing points of the path consist of two types of points:

- the information points, defining the information route
- the knowledge points, defining the knowledge route

The data on the information route are reinvested in the knowledge points where the learner transforms the information into knowledge. The knowledge point is a critical point structuring the path in sequences.

The successive sequences define a quest. The number of information points in each sequence is defined in relation to the riddle proposed and the number of knowledge points in a quest is defined by the message (religious, structural aspect, etc.) to be taught (fig. 1).

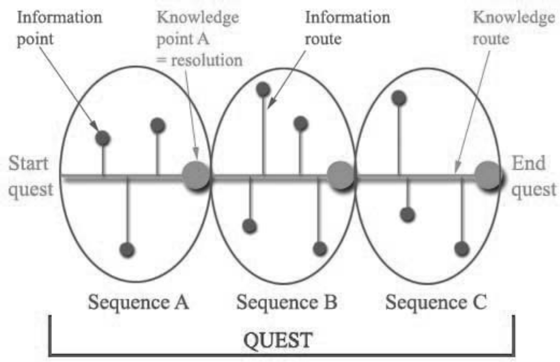

Fig. 1. Successive sequences of the path defining a quest.

2.2 The cognitive path

Research and cognitive experiments have shown that the learner must be constantly alerted and motivated to be interested in the studied topic. The acquisition of new knowledge depends on his willingness to achieve the objectives defined at the beginning.

To motivate the learner by avoiding a "cognitive overload" [1], we define a ludic aspect of the path in relation to the diversity of spaces that can be visited and in relation to the possible interactions in these spaces by manipulating multimodal information.

We decide to create some extensions of the path in the 3D base model. These spaces voluntarily added, fictitious or depending on the historical context of the building, belong to the information route and hold the clues for solving the riddle at the knowledge point and for moving to the next sequence. The knowledge points would thus be existing spaces in a building to be communicated. The transition between the existing spaces and added spaces is possible by crossing portals.

Imagine a path in the Cheops Pyramid in Egypt. The learner moves in real time in the existing spaces in the monument. He can take at any time inserted exterior spaces. By leaving the "King's Chamber", he could go for example to a mummification room of the second empire, to the Louvre Museum in Paris, to an invented virtual space allowing an interaction between the learner and his environment.

3 The memory map

During the creation activity, the learner outlines his path. Like a cartographer, he reveals his discoveries in order to establish a journal telling the story of his journey.

3.1 A multimedia notebook

According to David Cohen, multimedia has three components: Audiovisual, Interactivity and Network [2].

The memory map is a support crossing various graphic and sound representations: it allows the learner to store images, take notes, sketch drawings and play audio or video: multimodal information found during the 3D exploration or created by the learner. Information contained on the map is manipulated. Actions such as moving, connecting, correcting, removing, etc, maintain an interaction between information and the user.

The memory map is not a closed system with its own data library. Connections are possible with Internet. This concept of network extends the notions of space and distance between consulted information and the learner.

3.2 A locating tool

Outlining a path to explain where we have come from but also where we are going. In this context, a rapid movement system is thus established to navigate between the memory map and the 3D model. This feedback system is possible using sensitive areas. Teleportation provides a transfer between two points of view: an internal or subjective focus on the building and a zero focus around the memory map.

3.3 A memory tool

The memory map transmits messages. Its capacity to produce meanings allows the learner to build his own reasoning. According to Jean Piaget [3], knowledge results from the interaction between the person and the environment, compared to the constructivist hypothesis: we appropriate knowledge that we build ourselves.

The possible links between the information allow the learner to create associations between elements. This process is similar to the mnemonic method. This activity is a learning process by organizing information and by encouraging memorization.

4 A scenario in the Cheops Pyramid

A prototype is realized using the *Java* language in order to create the memory map and the level editor *Unreal Ed 4.0* (with the video game *Unreal Tournament 3* [4]) in order to create a 3D model of the pyramid (fig.2). The method consists in using the Internet protocols (*TCP* and *HTTP*) to put in relation the 3D model and the memory map.

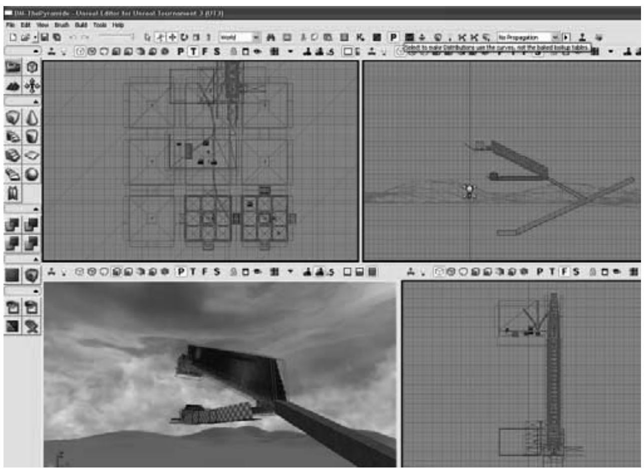

Fig. 2. The Cheops Pyramid in the level editor *Unreal Ed 4.0*.

The Great Pyramid contains many mysteries. Its architectural, symbolic or historic complexity, allows us to define several quests. In our study, we approach the religion of the pyramid.

4.1 Story of a journey into the afterlife

The pyramid is the funeral monument allowing the pharaoh to live eternally. The purpose of the quest is to reveal the journey of the pharaoh to reach the afterlife.

The learner will discover through the pyramid a considerable universe of symbols and religious practices assuring the rebirth of the deceased.

He will move in the monument with a subjective point of view embodying the soul of the pharaoh Cheops.

The quest possesses four riddles or four knowledge points (fig. 3):

- the entrance: the cosmos perceived from the Nile
- the Great Gallery
- the "Queen's Chamber": a path of obstacles
- the "King's Chamber": return to his sarcophagus without mistakes

Each solved riddle delivers a canopic jar to the learner. The four canopic jars collected allow him to reach the objective of the quest.

As an example, we will develop the knowledge point C.

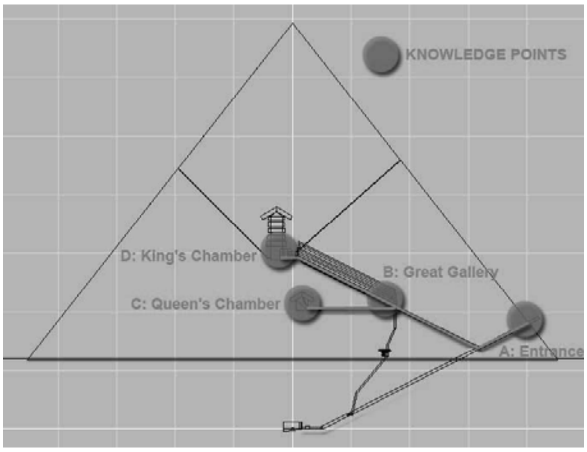

Fig. 3. The route of knowledge in the Cheops Pyramid.

4.2 The riddle of the "Queen's Chamber"

The "Queen's Chamber" has its name by mistake. In fact, the King's wives had their tombs near the Great Pyramid. This chamber, and in particular the North and South ducts, question researchers. These ducts are blocked by limestone doors possessing two copper handles.

The riddle is to discover the ducts and their astronomical and religious functions.

4.3 The information spaces

The number of information spaces results from the riddle of the chamber. We report three spaces and we will develop one to study the possible actions:

- Reading space: the invisible and immaterial entities of human being
- Immersion space: a journey by solar bark
- Logic and mechanism space: the weighing of the heart

This space informs about the ritual obstacles that the pharaoh must pass for his resurrection in the afterlife, materialized by the doors blocking the ducts.

In reference to the film *Cube* [5], the logic and mechanism space is constituted by attached boxes in three dimensions (fig. 4). These rooms and the passages assuring their communication are a labyrinth. They are a metaphor of traps and doors that the pharaoh must face.

The deceased must prove his purity by finding and reciting magic words. In the judgment room possessing scales, his weighed heart is then lighter than the feather of Maât.

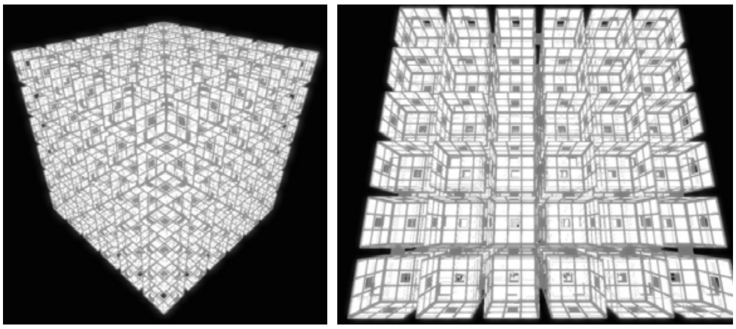

Fig. 4. The logic and mechanism space based on the film *Cube.*

The events are the following:

- The portal located in the horizontal corridor of the pyramid (fig. 5) teleports the learner to the first room. This room possesses an extract of the Egyptian *Book of the Dead* (Papyrus of Hunefer, British Museum, London) illustrating the weighing of the heart and the judgment.

Fig. 5. Teleportation portal located in the horizontal corridor.

- Each room possesses six doors with symbols based on the *Book of the dead*. The doors are present to guide the learner (fig. 6). There are the doors guarded by the hostile creatures Ammout and Apophis (crocodile, snake, insect, etc) and by passing through them, the learner is blocked in a room and is forced to come back.
- There are also the doors indicating the route of confession (feather, jar, etc). By passing through them, the learner discovers a fragment of papyrus mentioning a magic word to be recited ("I didn't incite to cry", "I didn't ordain to kill", etc).

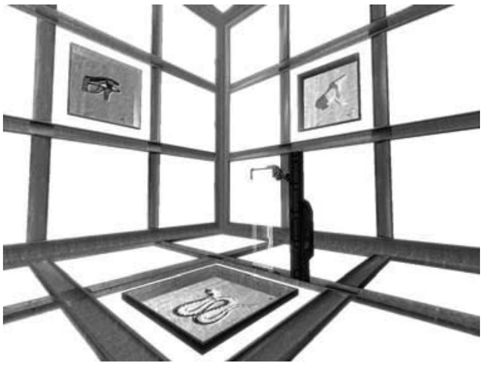

Fig. 6. A room and its doors in the logic and mechanism space.

- The route of confession leads to the judgment room. It possesses scales in its center, a feather and a jar. Forty two judges and five gods Anubis, Maât, Thot, Horus and Osiris (frescoes on walls) attend the weighing done by the learner.
- A portal allows the learner to return into the pyramid. Then, he explores the other information spaces or goes to the "Queen's Chamber" to resolve the riddle.

5 Correlation between the memory map and the strategic path

Each knowledge point allows the realization of a screenshot. It is a page of the memory map as a support of representation. When the learner visits the knowledge point, he initializes automatically the screenshot illustrating the space where he is (fig. 7). Thus, the number of knowledge point determines the number of pages of the memory map.

Fig. 7. A screenshot in the « Queen's Chamber ».

Then, the learner builds his relation to the spaces using words and images related with the information spaces: he clicks on the information to display on a page; he writes key sentences; he draws details or plans.

In the information space *Cube*, the learner first stores the papyrus discovered in the first room. Thereafter, he can relate the symbols perceived on the doors to those of the papyrus, he then sketches the plan of the labyrinth to find his way and he writes magic words to remember (Fig. 8).

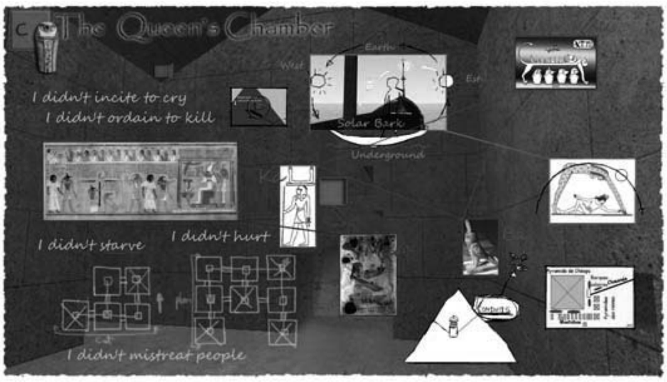

Fig. 8. A personalized screenshot.

Two types of links are managed in the system:

- The automatic links connect the information of the same space (2D links on a page) and the various knowledge points (3D links between pages).
- The personalized links created by the learner to connect similar elements.

When the riddle is solved, a canopic jar appears on the page.

The learner then begins the following sequence. He discovers the new riddle in the knowledge space and generates a new page of the memory map. The pages are added until the end of the quest (fig. 9).

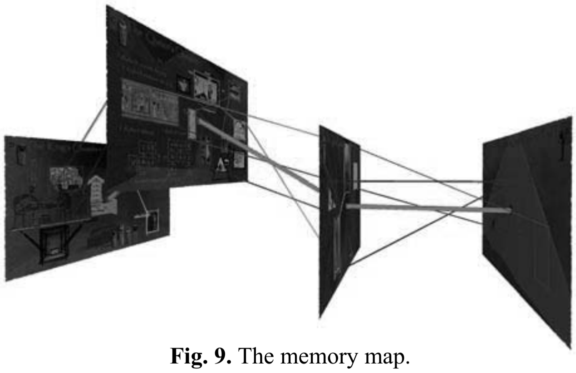

Fig. 9. The memory map.

A teleportation script (fig. 10) manages the transfers between the pages and knowledge spaces of the 3D model by clicking sensitive areas.

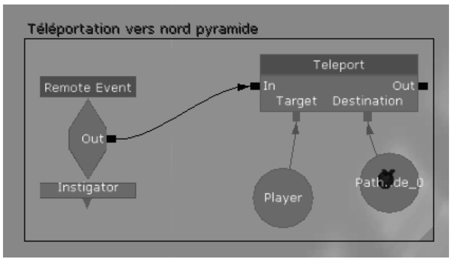

Fig. 10. A teleportation script in the level editor *Unreal Ed 4.0*.

6 Conclusion

During the visit of a 3D model, the exploration and creation activities allow us to elaborate a learning system supervising the navigation of the learner: by managing his movements and by taking into account his cognitive capacities.

We have seen how the creation of the memory map is based on the structure of the topographic and cognitive paths. The map accompanies the learner's exploration.

On the one hand, the paths manage movements and possible interactions in the spaces; on the other hand, the memory map retains traces as evidence of an exploration.

By producing meaning and by evoking his limits, the learner tries to master the unknown by his own representation.

Finally, the realization of the prototype shows some technical or screenplay problems. This prototype will allow us to validate or revise our work. An experiment is planned with students.

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Pédagogie

Pédagogie

Franck Besançon, Jean-Claude Bignon, Gilles Duchanois 132
Une méthode de modélisation croisée pour concevoir des structures en bois : "les défis du bois".
MC 2012, Lyon, France.

Résumé :
Ce document examine les différents modèles utilisés en situation de conception. Il s'appuie sur une expérience pédagogique menée depuis huit ans: «Les défis de bois." Cet atelier réunit pendant une semaine, une cinquantaine d'étudiants en architecture et en ingéniérie du bois. Une méthodologie de conception basée sur l'utilisation croisée de modèles nous permet d'imaginer et de simuler la construction d'une structure en bois inventive. En décrivant les différents modèles et les attributs qui leur sont rattachés, nous montrons que l'utilisation de ces modèles permet de fertiliser la transition d'une idée à sa matérialisation concrète.

D. Léonard, D. Conteau, G. Duchanois, O.Gamez, D. Hanser, P. Leclère 141
Taller Digital con Cabri gómetra.
IBERO CABRI 2012, Lima, Pérou.

Résumé :
Atelier numérique Cabri Géomètre.
Avec l'émergence des outils numériques et informatiques il est aujourd'hui possible de renouer avec une géométrie essentiellement graphique. Les méthodes traditionnelles permettant d'établir une volumétrie à partir d'un plan, instrumentée par la géométrie descriptive, font partie du savoir faire et de la formation des architectes ; elles sont essentielles pour permettre aux étudiants de cultiver leur « vision dans l'espace ». Certes les outils de modélisation géométrique professionnels instrumentent aujourd'hui les opérations qui étaient réalisées hier à la main, sur la table à dessin. La formalisation de ces opérations de manière analytique, ou leur réalisation au travers d'un langage de programmation ne présentent aucun intérêt pour des étudiants en architecture. En revanche, leur formalisation avec le support d'objets graphiques et leur intersection, dans le cadre de la géométrie dynamique, nous paraissent prometteuses et formatrices. Nous relatons ici une expérience d'utilisation de Cabri, dans le cadre d'un enseignement de 1ère année de géométrie descriptive ; cet enseignement se termine par un travail de réalisation de maquettes, à partir d'un plan cadastral, représentant un terrain sur lequel est implantée la volumétrie d'une maison d'habitation. Qu'il s'agisse du développé du terrain fabriqué à partir des données du plan cadastral ou de celui de l'enveloppe de la volumétrie de l'habitation et de son axonométrie, toute ces opérations peuvent être instrumentées informatiquement avec Cabri en utilisant les méthodes graphiques traditionnelles. Cette approche alliant tradition et modernité nous semble la plus prometteuse et porteuse de sens pour un enseignement de géométrie dans une école d'architecture.

Stéphane Safin, Sylvain Kubicki, Jean-Claude Bignon, Pierre Leclercq 148
Digital collaborative studio : 4 years of practice.
CAAD Futures 2011, Liège, Belgique.

Résumé :
Studio collaboratif distant : Quatre années d'expérience.
Nous rendons compte dans cet article court d'un travail pédagogique conduit depuis plusieurs années entre l'Ecole Nationale d'Architecture de Nancy , l'Université de Liège et le CRP Henri Tudor. Ce studio de conception vise à former des élèves architectes et ingénieurs au travail collaboratif en expérimentant différents outils numériques de travail à distance issus de la recherche.

Une méthode de modélisation croisée pour concevoir des structures en bois : les « défis du bois »

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Abstract. This paper discusses the different models used in design situation. It relies on a learning experience conducted for eight years: "Wood Challenges." This workshop meets for a week, fifty students in architecture and wood-engineering. A design methodology based on the use of models allows us to imagine and simulate the construction of a wooden inventive structure. In describing the various models and the attributes attached to them, we show that the use of these models allows cross-fertilize the transition from an idea to its concrete materialization.

Keywords: design process, models, architecture and wood ingeneering, learning experience

Contexte

Le système productif actuel dissocie de plus en plus fortement les compétences et engendre des discontinuités entre les acteurs que l'on tente de compenser par des méthodes et outils dits collaboratifs. Si la spécialisation des connaissances et des compétences est inhérente à l'évolution des pratiques humaines et à l'enrichissement des savoirs et des savoir-faire qui leur sont liés, la nécessité de leur assemblage ou tout du moins de leur intersection reste forte.

Dans le domaine de la production du bâti, les mêmes phénomènes de distanciation sont à l'œuvre avec des formes de surspécialisation dans les métiers. Il suffit d'observer comment toute nouvelle dimension de conception, par exemple la qualité environnementale, est aujourd'hui attribuée à un conseiller spécifique. On retrouve cette tendance dans l'enseignement. Architectes et ingénieurs sont formés séparément, tout du moins en France, et au sein de chaque formation les savoirs constitutifs de ces disciplines sont isolés et interagissent peu. Le processus de projetation allant de l'idée à la matière se fait par des séquences largement étanches qui parfois sont mises en opposition, préparant ainsi involontairement un terrain de méfiance voire de défiance entre les divers praticiens de la maîtrise d'œuvre. Les outils qui instrumentent ces pratiques finissent même par ne pas être interopérables tant les modèles sur lesquels ils se fondent sont différenciés.

La critique de ces pratiques n'est pourtant pas neuve. Jean Prouvé a largement tancé ces contemporains sur cette question en donnant au prototype un rôle central dans les pratiques de conception et de fabrication (Bignon 1990). Ezio Manzini a montré que le processus qui va du pensable au possible entremêle largement projet virtuel et matérialité (Manzini 1989). D'autres travaux plus récents ont fait apparaître que les différents médiums utilisés en conception et les modèles qui les sous-tendent ne pouvaient s'opposer ou se substituer l'un à l'autre. Par exemple, Pierre Côté a confirmé que la modélisation numérique ne peut ni se substituer au dessin manuel ni à la maquette (Côté 2011).

Hypothèse

Notre travail se fonde sur l'hypothèse qu'un croisement des outils de modélisation utilisés pour la production des ouvrages est de nature à fertiliser les démarches et augmenter la qualité des propositions. La question de la matérialisation peut alors être abordée à partir de cinq modèles différents : le modèle sémantique, le modèle analogique, le modèle géométrique, le modèle structurel et le modèle prototype, étant entendu que la réalisation finale finit récursivement par devenir elle-même le modèle du projet qui lui a donné naissance.

Chacun des modèles questionne et/ou solutionne une ou plusieurs dimensions de la matérialité. Par exemple, la question du poids des composants qui n'est pas présent dans le modèle géométrique est au contraire un attribut constitutif du modèle structurel. Deux modèles différents peuvent également avoir les mêmes attributs de matérialité, mais avec des valeurs ou des dégrés de certitude différents. Ainsi la question de la forme, très incertaine dans le modèle sémantique, devient quasiment figée dans le modèle prototype. Ce sont donc les attributs de la matérialité et leurs valeurs qui sont constitutifs de chacun des modèles. Ils guident les variations différentes du comportement des modèles et donc leur aptitude à permettre l'exploration et l'évaluation des propositions. Dans le présent travail, une liste de dix attributs permet de caractériser chacun des modèles et leur aptitude à représenter ces « être géométriques dans l'espace » identifiés par D.G. Emmerich dans la morphogenèse structurale (Emmerich 1971).

Nous avons formalisé cette approche dans une méthode qui est aujourd'hui utilisée pour mener les « défis du bois ». Appliquée et adaptée depuis huit années, elle permet une production rapide, inventive et partagée dans le cadre de cette manifestaition.

Les défis du bois

Les défis du bois sont un dispositif pédagogique visant à mobiliser des savoirs et savoir-faire, de l'intelligible et du sensible, pour concevoir et réaliser des structures inventives en bois. Il s'agit véritablement d'un atelier à tous les sens du terme. Atelier d'artiste, atelier d'artisan, atelier d'usine, bref c'est un lieu où sont rassemblés ceux qui conçoivent ou fabriquent un objet, voire une œuvre. Le protocole pédagogique proposé met en œuvre des pratiques de modélisation croisées de l'objet à concevoir et réaliser en abordant la question de la matérialité par la manipulation de données tantôt symboliques, tantôt iconiques, tantôt matérielles.

Initié par l'ENSA-Nancy et l'ENSTIB en 2005, cet atelier didactique rassemble près d'une cinquantaine d'étudiants, pour moitié élèves architectes et pour moitié éléves ingénieurs en provenance de différents pays. Organisés en dix équipes mixtes, ces étudiants doivent concevoir et réaliser en une semaine une structure en réponse à un sujet qui leur est révélé le jour du démarrage de l'épreuve en faisant appel à un outillage et à une quantité de matériaux limités et identiques pour tous. (www.defisbois.fr)

Figure 1 – Défis du bois 2012 : un rayon pour chacun, un soleil pour tous

Le modèle en conception

S'il est admis que, d'une manière générale, nous raisonnons sur des modèles (Valéry1973), il convient cependant d'apporter quelques précisions sur le rôle des modèles. Dans notre contexte expérimental, le modèle doit être appréhendé comme une représentation simulante et stimulante . Comme le modèle scientifique, le modèle en conception permet de décrire et de prédire un fait, un comportement, une réalité au sens large. Mais il permet aussi de construire par la pensée cette réalité qui n'existe pas ou pas encore. Il s'agit moins d'établir la connaissance d'un objet que de produire la connaissance d'un projet (Le Moigne 1989).

La perception de l'objet à construire qui s'établit dans le modèle va pouvoir prendre des formes ou plutôt des formalisations variées. Le modèle pourra se construire sur des données symbolique avec une forme d'abstraction importante par rapport au matériau ; c'est le cas du modèle sémantique ou du modèle structurel. Il pourra au contraire s'établir sur des données iconique avec une correspondance visuelle plus forte, comme c'est le cas du modèle analogique ou du modèle géométrique. Le prototype représente, quand à lui, une forme hybride de modélisation, en combinant une expérience « vraie » de la structure fondée sur des données matériaulogiques et des représentations symboliques qu'elles soient mathématiques ou sémantiques.

Les modèles de conception vont également entretenir des rapports à la matérialisation de l'idée à des degrés différents. Si le modèle sémantique est très distant et incertain sur la matérialité, le modèle prototype, lui, se confond presque avec cette matérialité. Dans une conception expérimentale comme la nôtre, la question de l'ambiguïté du modèle ne se pose pas comme dans le domaine des sciences. Au contraire, selon les moments du processus de conception et les modèles convoqués, l'ambiguïté peut être favorable à une attitude projective. Le « flou » du modèle sémantique est indispensable pour activer l'imaginaire et permettre des dérivations nombreuses nécessaires à la recherche de la solution. Tandis que la précison du modèle prototype est utile à la finalisation du projet.

La dernière question sera celle de la justesse du modèle. Si le principe de preuve peut être convoqué dans le modèle physique, il est difficilement applicable au modèle sémantique et finalement au projet comme modèle à construire. Certes, la construction réelle pourra participer à la vérification de certaines pertinences, comme par exemple la stabilité, mais elle ne saurait argumenter l'acceptation ou la réfutation globale de la proposition (Popper 2006). L'œuvre réalisée sera ou ne sera pas (pour ceux qui ont échoué), mais elle ne sera pas une preuve pour les modèles utilisés. Finalement on constatera que les modèles en conception sont d'abord des outils projectifs avant d'être des outils analytiques.

La combinaison de différents modèles dans l'activité des « défis du bois » nous permet d'asseoir la multiplicité des points de vue, en particulier celle des architectes et des ingénieurs. Elle favorise une approche sélective, mais différenciée des informations indispensables à la conduite du travail de conception. Elle autorise une évaluation réciproque en permettant également de compenser l'incomplétude de chaque modèle et leurs inadéquations à répondre à toutes les questions posées lors de la conception. Elle permet enfin d'enrichir le processus de conception en situation expérimentale, en limitant les approches routinières et en favorisant la capacité d'invention.

Le modèle sémantique

Le modèle symbolique associe librement des mots et des croquis rapides pour permettre à l'équipe de conception de clarifier un « concept » partageable. Le modèle se formalise ici à partir de deux types de signifiants appartenant au langage et à la figuration naturels. Les premiers sont des mots empruntés au vocabulaire courant. Ceux-ci peuvent avoir des caractères d'abstraction du réel très différenciés. Par exemple, le mot « légèreté » porte une ouverture sémantique plus large que le mot « escalier ». Les seconds sont des « traces » ou « icones », ils échappent à la figuration codée, mais affinent le sens des mots auxquels ils sont liés ou apportent un signifié que le mot peine à exprimer.

Par cette formalisation abstraite, le modèle sémantique autorise un premier niveau d'échange du concepteur avec lui-même et des concepteurs entre eux. Le modèle sémantique est un dispositif d'explicitation incertaine qui permet rapidement d'ouvrir le champ du pensable et du dessinable et de contourner le syndrome de la page blanche.

Nous utiliserons le modèle sémantique pour « mettre en condition » de création l'équipe de conception. Il s'agit de parvenir à dégager un maximum d'hypothèses au sein de l'équipe. L'intérêt porté à ce modèle réside dans sa facilité d'accès. La parole a la capacité de renvoyer rapidement et mentalement à une image, un son, des couleurs…, autant d'éléments à interpréter et de déclinaisons possibles qui deviennent dessinables pour démarrer la conception.

Dans ce modèle, la matière est largement symbolique. Elle renvoie à des images puisées dans des univers référentiels très différents. Le bois peut évoquer l'arbre ou la forêt, la verticalité du tronc et le flou de la canopée. Mais il peut également évoquer le ciel et la terre, le feu et la vie, la cabane primitive ou le temple grec. La représentation formelle donnée au mot enlève une part d'abstraction et précise l'intention, l'idée qu'il faudra développer. Une ligne ondulante, un élancement, un éclatement… représente des formes géométriques simples ou complexes qui font entrer le projet dans le domaine du pensable. La matière prend forme en même temps qu'elle prend nom pour finalement prendre sens.

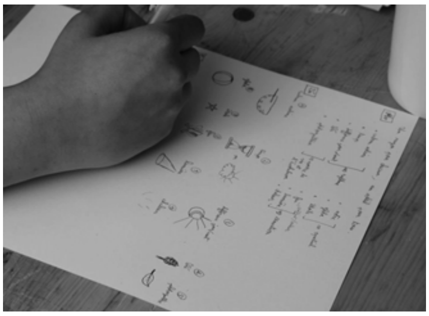

Figure 2 - modèle sémantique : des mots et des traces graphiques

La réflexion passe de l'imaginable au pensable. L'échange d'informations orales dans l'équipe donne des indications qui ne figurent pas dans le dessin ou qui précisent les mots. La matérialité commence à prendre la forme d'une matière signifiante intégrable dans le projet. Le collectif de conception doit alors gérer et filtrer la quantité d'éléments incertains et complexes introduits dans le modèle.

Le modèle analogique

Le modèle analogique représenté par la maquette physique est un modèle qui se caractérise par des analogies de comportements ou de formes proches de l'objet réel. Karen Moon nous rappelle que la maquette a toujours été un moyen pour les architectes de développer et communiquer leurs idées, parce qu'elle constitue le passage à la volumétrie par la 3D (Moon 2005). La maquette spatialise les idées souvent représentées en deux dimensions (Schilling 2007). Cependant, le niveau de détail et de prise en compte de la matière va dépendre principalement de l'échelle utilisée.

Nous utilisons deux sortes de maquette dans notre travail. La première est dite conceptuelle. Elle est sans échelle véritable et se trouve dans un prolongement du modèle sémantique. Elle concrétise la pensée par un volume en trois dimensions en associant des matériaux qui pourront ou non se rapprocher de ceux utilisés au final. Sans être dépourvue de matérialité, elle conserve une part d'abstraction de la matière qui permet de développer plusieurs idées constructives ouvrant toujours le champ des possibles. Au travers du modèle ainsi produit, l'équipe de conception s'attachera à structurer la forme pour la rendre réalisable, puis fabricable.

La seconde maquette est dite de composition. Elle peut être réalisée sous forme d'une autre maquette que la maquette conceptuelle ou venir la « reprendre » Dès lors, la prise en compte de la matière devient de plus en plus précise. Le niveau de détail va dépendre principalement de l'échelle utilisée. La maquette devient support de nombreuses informations. Il y a à la fois l'information réelle comme la position des composants dans ce que montre l'objet avec l'éxecution de détails soignés, mais aussi l'information de ce qui n'est pas montré, mais seulement suggéré par les matériaux qui seront utilisés. La colle, par exemple, traduit un assemblage qu'il faudra résoudre.

Dans ce modèle, la matière va jusqu'à la miniaturisation (qui semble nécessaire) du matériau final dans ses rapports de longueur, largeur et épaisseur. Pourtant si la nature du matériau utilisé pour la maquette est identique à celle du matériau final, l'analogie avec le reel potentiel reste partielle. En conception, le modèle analogique n'est pas une simple réduction. Une volige de 4 mètres de long n'a pas le même comportement qu'une pièce de bois de 20 centimètres, même si sa section est proportionnelle.

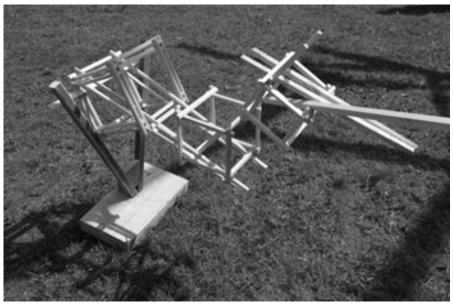

Figure 3 - modèle analogiqique : une première forme de matérialisation

La maquette trouve aussi sa pertinence dans une première approche de la stabilité et de l'assemblage offert par la lecture directe. En manipulant physiquement le modèle créé, on peut expérimenter avec une première approximation son comportement. L'observation et l'analyse des déformations du modèle renverront à l'utilisation d'autres modèles comme le modèle structurel et/ou à la reprise de la maquette. Dans le modèle analogique, la matière devient « visualisable » et le projet devient davantage constructible avec le montage qui transparaît en filigrane.

Le modèle géométrique

La modélisation géométrique est l'ensemble des outils mathématiques, numériques et informatiques qui, combinés, permettent de construire un modèle virtuel (ou modèle informatique) d'un objet réel. Elle sous-entend d'être en mesure de réaliser la construction et l'assemblage de formes élémentaires pour créer des objets de plus en plus complexes en respectant des contraintes topologiques.

Le modèle géométrique permet d'assurer une représentation tridimensionnelle qui favorise la compréhension de l'objet, notamment sur la forme, les connexions… Cet objet peut être le fruit de l'imagination ou l'expression d'une solution plus ou moins exacte d'un problème physique donné, voire un compromis entre les deux. Le modèle créé est une représentation « probable » de l'objet avec un dimensionnement « vraisemblable » des composants donnés au départ. Comme la maquette, le modèle géométrique permet des manipulations pour représenter, modifier, analyser, manipulations souvent facilitées par la capacité des modeleurs à favoriser le choix des points de vue et le niveau de focalisation. Par différence avec le modèle analogique, la paramétrisation des composants (par exemple les sections) peut favoriser le travail de recherche de solutions par ajustement.

Figure 4 - modèle géométrique : une maquete virtuelle

Du côté de la fabrication, le modèle géométrique donnera une information réelle vis-à-vis de la matière en renseignant les angles de coupes, les longueurs des pièces ou le nombre total d'éléments. Il peut même dans certains processus « numériques continués » fournir les données d'entrées pour des machines à commande numérique. Ce n'est pas l'objet des « défis du bois », car nous voulons privilégier un rapport du projet à l'objet qui sera aussi tactile.

Le modèle structurel

Le modèle structurel permet une compréhension et une simulation du comportement de la structure en terme de stabilité et de résistance des matériaux. Il fait appel à différentes théories issues de la physique des matériaux et des structures comme la « théorie des poutres » ou des méthodes calculatoires comme le « calcul aux éléments finis ».

Figure 5 - modèle structurel : l'usage du calcul scientifique

Sur le plan iconique, le modèle s'appuie sur une abstraction des composants en réduisant leur forme à un axe et une section et leur liaison à un nœud. Sur le plan sémantique les liaisons sont caractérisées par un comportement mécanique (encastrement, rotule…) tandis que la matière y est abordée par son module d'élasticité. Le modèle structurel est donc une abstraction par rapport au modèle analogique et au modèle géométrique dont il reprend les attributs, mais avec une valuation différente. Celle-ci enrichit la compréhension du comportement physique de la structure, mais elle peut aussi perdre de l'information antérieure. Sur la technologie de l'assemblage par exemple, le modèle analogique peut porter une information qui se perd dans le modèle structurel. Ainsi, l'usage de fils pour liaisonner les composants d'une maquette peut caractériser une ligature, alors qu'une épingle simulera une tige filetée.

Le modèle structurel contraint également à un raffinement des composants en obligeant à les dissocier. Il devient possible de décomposer le modèle en identifiant chacune de ses entités et ainsi d'entrevoir la faisabilité constructive de l'objet en conception. La matérialisation devient « structurellement réaliste ».

Enfin, la simulation structurelle favorise la visualisation des efforts et de la déformation de la structure. Elle asseoit la compréhension dynamique de l'ouvrage à dimensionner.

Le modèle prototype

Le modèle prototype permet d'expérimenter par le « travail grandeur nature » les multiples valeurs des attributs de la matérialité des autres modèles en apportant une dimension tactile et corporelle indispensable.

Il joue un rôle empirique dans la vérification du dimensionnement en complément du modèle structurel en permettant d'éprouver physiquement des valeurs qui sont trop souvent abstraites pour les étudiants. Avec des tests à l'échelle 1/1, il permet d'accéder efficacement à une solution en facilitant la compréhension de la structure par l'expression concrète des déformations et l'approche des singularités du matériau bois. La matière se révèle et ce qui était pensé comme léger devient parfois lourd, le raide devient souple et gauche, le cintrable devient rigide, le solide et résistant devient fragile et cassant.

Le prototype donne par ailleurs une autre approche constructive que la maquette en intégrant les problèmes réels de poids et d'encombrement, mais aussi ceux liés à l'usinage et au levage. La réalisation du prototype invite à penser la chronologie de fabrication et de montage. Les questions de découpage de l'objet apparaissent en distinguant ce qui est fait au sol et ce qui est fait en l'air avec les problèmes de fixations et de facilité d'accès. Le modèle intègre aussi des « composants éphémères » pour l'étaiement, le contrôle de l'équerrage ou encore pour le levage.

Figure 6 - modèle prototype : la matière en essais

On notera enfin que le contact réel et concret avec le matériau n'intervient pas seulement à la fin du processus de conception. Le modèle prototype n'est pas réservé à la réalisation de l'objet final, il se veut permanent dans le processus de conception, en renseignant les autres modèles et en opérant la liaison entre le pensable et le réalisable.

Conclusion

En nous appuyant sur une expérience pédagogique menée depuis huit ans, nous avons tenté de formaliser un processus de conception/fabrication en tant que processus de matérialisation d'idées. Cette approche se fonde sur l'utilisation croisée de cinq modèles caractérisés chacun par des attributs de matérialité. La figure 7 présente un tableau récapitulatif de ces attributs, leur présence et leur valeur dans chacun des modèles. On remarquera que si le modèle sémantique comporte peu d'attributs, ceux-ci sont particulièrement critiques en début de processus. A l'opposé, le modèle prototype comporte beaucoup d'attributs qui le place souvent en fin de process, même s'il est partiellement utilisable avant.

Modèles / *Attributs*	SEMANTIQUE	ANALOGIQUE	GEOMETRIQUE	STRUCTUREL	PROTOTYPE
Symbolique	***	**	*		*
Forme	*/**	***	***	***	***
Dimension	*	**	***	***	***
Poids				**	***
Position		**	***	***	***
Relation (topologie)		**	***	***	***
Mécanique		**		***	***
Stabilité		*		***	***
Fabrication		*	*		***
Montage		*	*		***

Figure 7 - Tableau récapitulatif des modèles et du degré de caractérisation des attributs

Loin d'être linéaire, ce processus de matérialisation d'une forme structurelle par usage de modèles différenciés se révèle largement opportuniste. Ce sont les différentes questions posées par la matérialité qui appellent l'usage de l'un ou l'autre des modèles. Les outils numériques (modeleurs géométriques, simulation de structures…) dans un tel dispositif ne se substituent pas aux autres moyens de compréhension et d'échanges, mais viennent les enrichir. Rarement premiers, ils sont aussi rarement derniers dans le processus de conception. La matière ne saurait jamais être totalement dématérialisée.

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Taller Digital con Cabri gómetra

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RESUMEN

Con la aparición de las herramientas digitales e informáticas, hoy día es posible reencontrarse con una geometría esencialmente gráfica.

Los métodos tradicionales que permiten establecer una volumetría a partir de un plano, alimentado a través de la geometría descriptiva, hacen parte del "saber cómo" y de la formación de los arquitectos; estos métodos son esenciales para permitir a los estudiantes de mejorar y/o cultivar su "visión en el espacio".

En efecto, las herramientas profesionales de modelización geométrica utilizan actualmente operaciones que otrora se realizaran a mano, en la mesa de dibujo. La ejecución de estas operaciones de manera analítica, o su realización a través de un lenguaje de programación no presentan interés alguno en los estudiantes de arquitectura. Sin embargo, el empleo de estas herramientas con el apoyo de objetos gráficos y su inclusión, en el área de la geometría dinámica, nos parecen algo no solo formador sino prometedor.

En este documento exponemos una experiencia con Cabri, en el marco de una clase de primer año de geometría descriptiva; este curso se concluye con la realización de un trabajo expresado en maquetas, las cuales se construyen con base en un plano catastral representando un terreno sobre el cual se implanta la volumetría de una o varias casas de habitación.

Se trate del desarrollo del terreno fabricado a partir de los datos entregados a través del plano catastral o de la piel de la volumetría de una casa y su axonometría, todas estas operaciones pueden ser implementadas a nivel informático con Cabri utilizando los métodos gráficos tradicionales.

Este enfoque que reúne lo tradicional y lo moderno nos parece el más prometedor y acertado para la enseñanza de la geometría en una escuela de arquitectura.

Eje temático: Arquitectura y diseño gráfico con la asistencia de Cabri

Palabras Clave : Didáctica, geometría descriptiva, geometría pura, arquitectura, modelización, prototipos, maquetismo.

INTRODUCTION

Avec l'émergence des outils numériques et informatiques il est aujourd'hui possible de renouer avec une géométrie essentiellement graphique.

Les méthodes traditionnelles permettant d'établir une volumétrie à partir de **données sur le plan**, instrumentée par la géométrie descriptive, font partie du savoir faire et de la formation des architectes ; elles sont essentielles pour permettre aux étudiants de cultiver leur « vision dans l'espace ».

Certes les outils de modélisation géométrique professionnels instrumentent aujourd'hui les opérations qui étaient réalisées hier à la main, sur la table à dessin. Faut il pour autant renoncer à l'apprentissage de ces opérations qui permettent de comprendre et maîtriser les questions d'échelles, ***d'élaborer la mise en relation de l'imaginaire avec le réel*** mais aussi de cultiver la vision de et dans l'espace ? Leur formalisation de manière analytique, ou leur réalisation au travers d'un langage de programmation ne présentent aucun intérêt pour des étudiants en architecture. En revanche, leur formalisation avec le support d'objets graphiques et leur intersection, dans le cadre de la géométrie dynamique, nous paraissent prometteur et formateur.

Nous relatons ici une expérience d'utilisation de Cabri, dans le cadre d'un enseignement de 1ère année de géométrie descriptive ; cet enseignement se termine par un travail de réalisation de maquettes, à partir d'un plan cadastral, représentant un terrain sur lequel est implantée la volumétrie d'une maison d'habitation.

Qu'il s'agisse du développé du terrain fabriqué à partir des données du plan cadastral ou de celui de l'enveloppe de la volumétrie de l'habitation et de son axonométrie, toute ces opérations peuvent être instrumentées informatiquement avec Cabri en utilisant les méthodes graphiques traditionnelles.

Cette approche alliant tradition et modernité nous semble la plus prometteuse et porteuse de sens pour un enseignement de géométrie dans une école d'architecture.

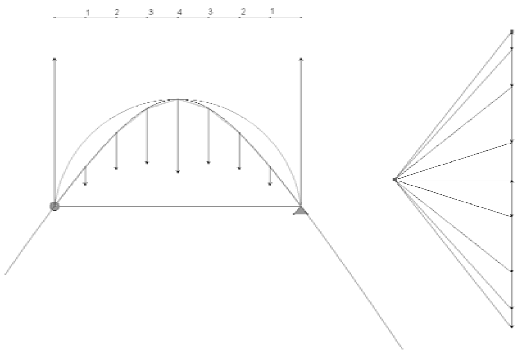
VARIATIONS PEDAGOGIQUES ET QUESTIONNEMENT

Il est désormais banal d'affirmer que les outils numériques de modélisation ont pris une place déterminante dans le processus de conception et de fabrication et l'architecture n'échappe pas à cette évolution. Les géométries, qu'elles reposent sur la notion de distance (euclidiennes et non euclidiennes) affines ou topologiques, et les algorithmes de transformation qu'elles sous-tendent, sont au cœur de ces outils. Il paraît tout autant indiscutable d'affirmer que la modélisation de ces géométries, notamment les géométries métriques, dans le cadre de l'informatique, est essentiellement analytique. Pourtant, le dessin géométrique, que nous appellerons ici construction géométrique et qui repose sur une géométrie classique du tracé, nous paraît être un élément essentiel à la formation des architectes. Ainsi, Il paraît naturel, au moins dans le cycle licence, d'appuyer l'enseignement de la géométrie en privilégiant les objets géométriques classiques (droite, courbe, plan, surface, espace) se fondant dans une tradition qu'il est convenu d'appeler la « géométrie pure » ; cette géométrie peut se satisfaire aujourd'hui pleinement de la géométrie dynamique qui repose certes sur l'analyse mais qui offre à manipuler les éléments de la géométrie pure.

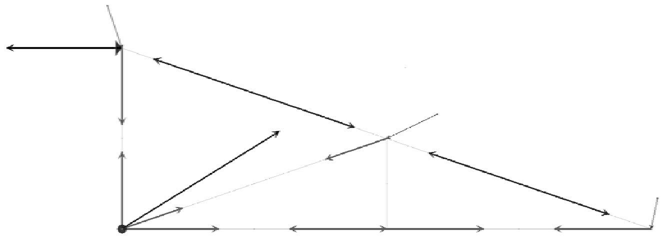
Ce faisant, pour peu que l'outil soit suffisamment souple et la construction géométrique correcte, le « dessin », parce que paramétré par les éléments de base qui le composent, peut naturellement être modifié par la variabilité des éléments de base ouvrant ainsi de nouvelles perspectives didactiques.

Résolution par calcul ou par construction géométrique

Un exemple mettant en jeu la dialectique graphique/numérique est celui de la résolution et du calcul ; le contexte ici est celui d'un enseignement de structure de première année. Les méthodes graphiques pour résoudre les problèmes de cette nature comme les méthodes analytiques sont bien connues ; ici encore, qu'il s'agisse de fermeture de dynamique et de calcul vectoriel la résolution sous forme graphique nous paraît plus directe, permet la visualisation des phénomènes et nous paraît plus pertinente pour la culture des futurs architectes ; pour peu que l'on utilise un support dynamique permettant de faire varier les conditions initiales, il devient possible de visualiser des phénomènes et/ou d'approcher une solution optimale. Du fait d'être supportée numériquement, cette approche par le graphique conduit à construire des solutions aussi précises qu'avec une approche calculatoire analytique.



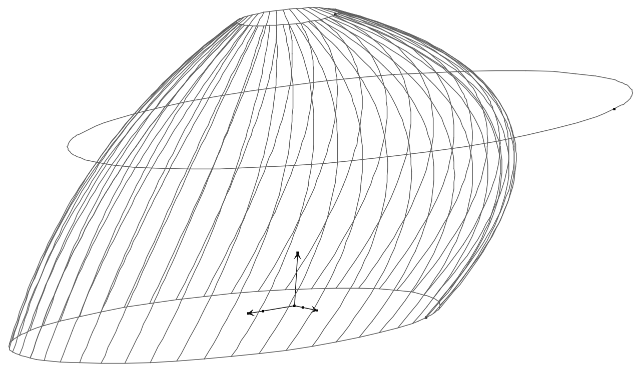
Forme idéale d'une voûte du point de vue des efforts ; application de la méthode du funiculaire avec Cabri ;



Décomposition/recomposition dynamique des forces dans les barres d'une console ; la géométrie dynamique permet de dynamiser la figure et d'observer les phénomènes de traction/compression.

Vers les « formes libres »

Un autre exemple se rapporte aux formes « libres » ou « complexes » ; la conception spatiale instrumentée informatiquement a vu émerger depuis une vingtaine d'années des formes nouvelles, parfois qualifiées d'*architecture blob*, *liquide*, *à forme libre*, *numérique*, *paramétrique* ou encore *non standard*. Il n'est pas question ici d'apporter un regard critique sur ces productions ; du point de vue géométrique, en introduisant le mouvement, sans connaissances pointues en programmation et en géométrie analytique, en s'appuyant sur l'intuition, il est possible d'atteindre rapidement des formes dites non standard ; l'exemple ci-dessous s'appuie mathématiquement sur la notion de distance et celle de barycentre. Il correspond à la notion de balayage d'une courbe sur deux rails implantée dans des logiciels tels que Rhino et Grasshopper (Payne, A., & Issa R.) ; à la différence de ces outils de modélisation qui fonctionnent comme des « boites noires », la projection d'une telle enveloppe dans le cadre de la géométrie dynamique avec Cabri est complètement construite et maîtrisée par l'étudiant, de la construction de la courbe de Bézier paramétrée à partir de trois points, de celles des cercles supports aux points de contrôle mais aussi à la projection axonométrique elle-même. La forme ci-dessous, du fait des courbes de Bézier, recèle une certaine complexité. L'étude des surfaces réglées **et/ou** de révolution sont un préalable et ne posent pas de difficulté.



Projection axonométrique d'une forme obtenue par balayage, sur trois rails, d'une courbe de Bézier de degré 2 avec Cabri ; qu'il s'agisse de la courbe obtenue comme lieu de points barycentre des trois points de contrôle, des cercles comme lieu de points équidistants de points donnés, mais aussi de la projection axonométrique sur le plan, tout participe d'une construction géométrique sur le plan.

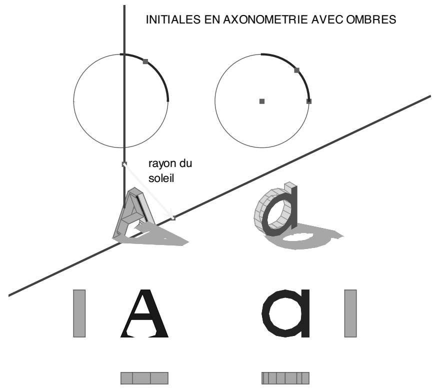
TRADITIONS ET MODERNITES

Nous utilisons depuis plusieurs années la géométrie dynamique dans un travail d'apprentissage sur les projections conventionnelles, qu'elles soient parallèles ou centrales (cf. ci-dessous travaux d'étudiants sur des perspectives construites à partir de Cabri Géomètre) ; la projection de l'espace sur le plan et la visualisation de l'espace à partir de sa projection sont des éléments d'enseignement traditionnels dans une école d'architecture. Très récemment, nous utilisons Cabri Géomètre dans un autre contexte traditionnel, celui de la géométrie descriptive et de la fabrication digitale.

Projections parallèles et centrales

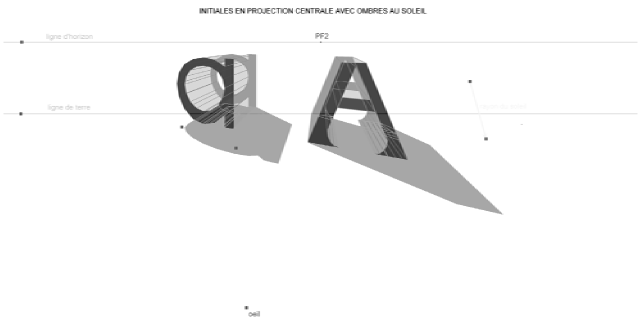
L'axonométrie, en tant que projection parallèle orthogonale, est l'un des modes de représentation traditionnel de l'architecture (Choisy A.). L'instrumentation dynamique de cette projection permet à l'étudiant de pleinement prendre conscience que l'axonométrie n'est pas l'espace mais une image de celui-ci par projection.

Le logiciel Cabri se substitue à la feuille de dessin et permet de travailler dans le plan comme on le ferait sur une table à dessin. Pourtant, du fait de la géométrie dynamique, à condition cependant que la construction géométrique soit correcte, la projection peut être modifiée par rotation du repère autour de l'axe des z et des y ; on reconstruit ainsi les conventions habituelles de mobilité d'un modeleur géométrique qui préserve l'axe des z .



Travail sur l'axonométrie orthogonale ; la direction de projection est orthogonale ; le plan de projection est oblique ; il a subi deux rotations, l'une autour de l'axe de z et l'autre autour de l'axe des x. La construction géométrique est plane. Les principes géométriques à la base de cette construction sont proches de ceux utilisés avec la planche à dessin (compas, parallélisme, intersection, …)

L'apprentissage de la projection centrale ou perspective conique est tout aussi efficace avec la géométrie dynamique ; la démarche didactique est tout à fait analogue à la précédente du point de vue de l'instrumentation avec la géométrie dynamique. Les paramètres ici, au lieu d'être la position relative du plan de projection par rapport au plan frontal qui caractérise l'axonométrie orthogonale, sont la position du centre de la projection et la position relative de l'objet par rapport à ce centre et au plan de projection.



Projection centrale paramétrée par la position du centre de la projection et par la position de l'objet à projeter. Ici aussi, même si certaines constructions peuvent être mémorisées pour ensuite être réutilisées, les principes géométriques à la base de cette construction sont proches de ceux utilisés avec la planche à dessin (compas, parallélisme, intersection, règle …).

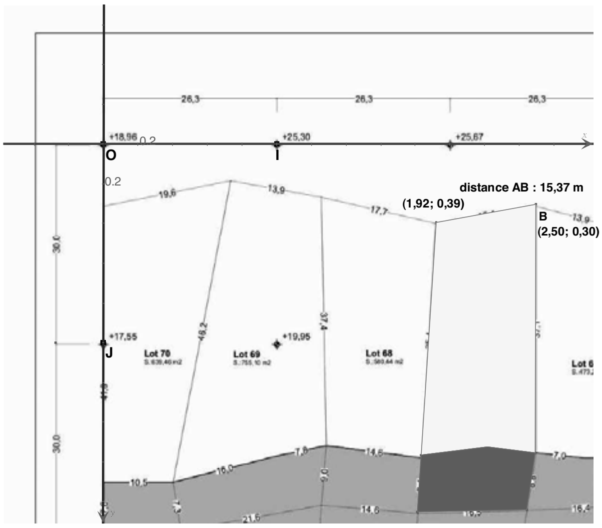
Conception et fabrication numérique

Cette année nous avons mis en place une nouvelle expérimentation dans l'utilisation de Cabri, celle de l'apprentissage de la « vraie grandeur » et de la fabrication de la maquette 3D ; le « projet » consiste, à partir d'un règlement d'urbanisme et d'un plan de cadastre, a demandé de fabriquer des enveloppes à l'échelle 1/200ème

Traditionnellement et historiquement, le travail est instrumenté graphiquement, via des techniques de géométrie **descriptive** ; il est aujourd'hui largement supporté par des modeleurs 3D. Nous rencontrons des difficultés **pédagogiques** à la fois dans l'apprentissage de la géométrie descriptive que les étudiants trouvent trop abstraite et dans celui des outils informatiques de modélisation et de transformation des modèles en vue de la fabrication, ***notamment au niveau des échelles***, qui plus est quand les étudiants ne disposent pas d'une culture géométrique suffisante. Pourtant, la modélisation et la production architecturale contemporaine est aujourd'hui une fervente utilisatrice de ces logiciels de modélisation et de fabrication. Aussi nous avons décidé de nous situer cette année à un niveau intermédiaire, celui de l'utilisation de la géométrie dynamique dans un contexte de modélisation et fabrication numérique et c'est à l'étudiant de fabriquer son outil numérique. Nous espérons que ce travail sera une bonne introduction à l'utilisation de modeleurs et d'outils de fabrication spécifiques et dédiés (Shadkhou, S., & Bignon, J.C.) en cycle master.

Echelle cartographique, mesure géométrique.

En utilisant un fond de plan dans la page de Cabri Géomètre on peut instrumenter la saisie digitale des parcelles ; et l'on est confronté aux mêmes problèmes d'échelle qu'avec un outil dédié ; cependant, comme le travail s'effectue dans le contexte de la géométrie, l'embrayage vers ce domaine est plus opérant.



Extrait du parcellaire sur lequel les étudiants travaillent ; mise en place d'un système d'aide à la saisie assisté par Cabri qui s'appuie sur une distance qui respecte l'échelle cartographique.

Du plan à la volumétrie

En instrumentant la géométrie descriptive dans Cabri il est possible de passer d'une représentation avec une double vue à la vue plus « naturelle » en axonométrie.

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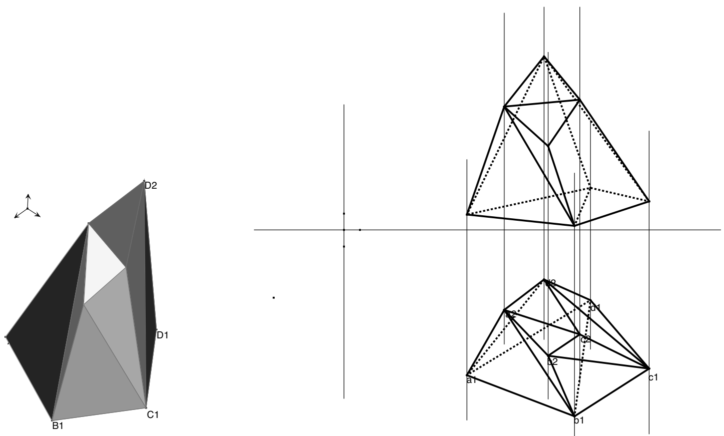

Passage d'une représentation conventionnelle à une autre ; ici le passage s'effectue de l'épure vers l'axonométrie. L'axonométrie est déterminée par l'image, par projection parallèle, d'un repère orthonormé. Les coordonnées mesurées dans l'épure sont tout simplement reportées graphiquement dans l'axonométrie ; la possibilité de mémoriser des constructions géométriques permet d'automatiser ce passage et d'éviter son côté répétitif et fastidieux.

Du plan à la vraie grandeur

La fabrication de la « vraie grandeur » peut s'effectuer, via Cabri, soit en utilisant la distance dans l'espace, soit par des techniques de géométrie descriptive. Le patron (développé) de la forme peut ensuite être défini, imprimé, et fabriqué.



Conclusion

Nous avons voulu, dans cet article, à la fois relater les différentes expériences d'utilisation de la géométrie dans nos différents enseignement à l'école d'architecture de Nancy mais aussi questionner les fondements d'un enseignement de la géométrie dans une école d'architecture ; nous sommes convaincus de l'intérêt pédagogique de l'utilisation de la géométrie dynamique et graphique dans une école d'architecture car elle permet des activités basées sur le trait plutôt que sur le nombre et s'inscrit naturellement dans une tradition de l'utilisation et de l'enseignement de la géométrie en architecture ; en permettant la dynamique, la paramétrisation et la prise en compte du mouvement, elle ouvre vers les productions de formes les plus actuelles.

Nous avons orienté l'apprentissage de la représentation architecturale à l'école d'architecture de Nancy en première année sur l'utilisation de la feuille de papier, à main levée ou à la règle et à l'équerre ; l'enseignement de la géométrie fait exception ; il est cependant une introduction et un préalable nécessaires pour pouvoir aborder comprendre et maîtriser les logiciels spécialisés, qu'ils s'agissent des modeleurs volumiques et surfaciques, en particulier l'association Rhino et Grasshopper qui est, de fait, un autre logiciel de géométrie dynamique.

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Distant Collaborative Studio : 4-year of practice

POSTER

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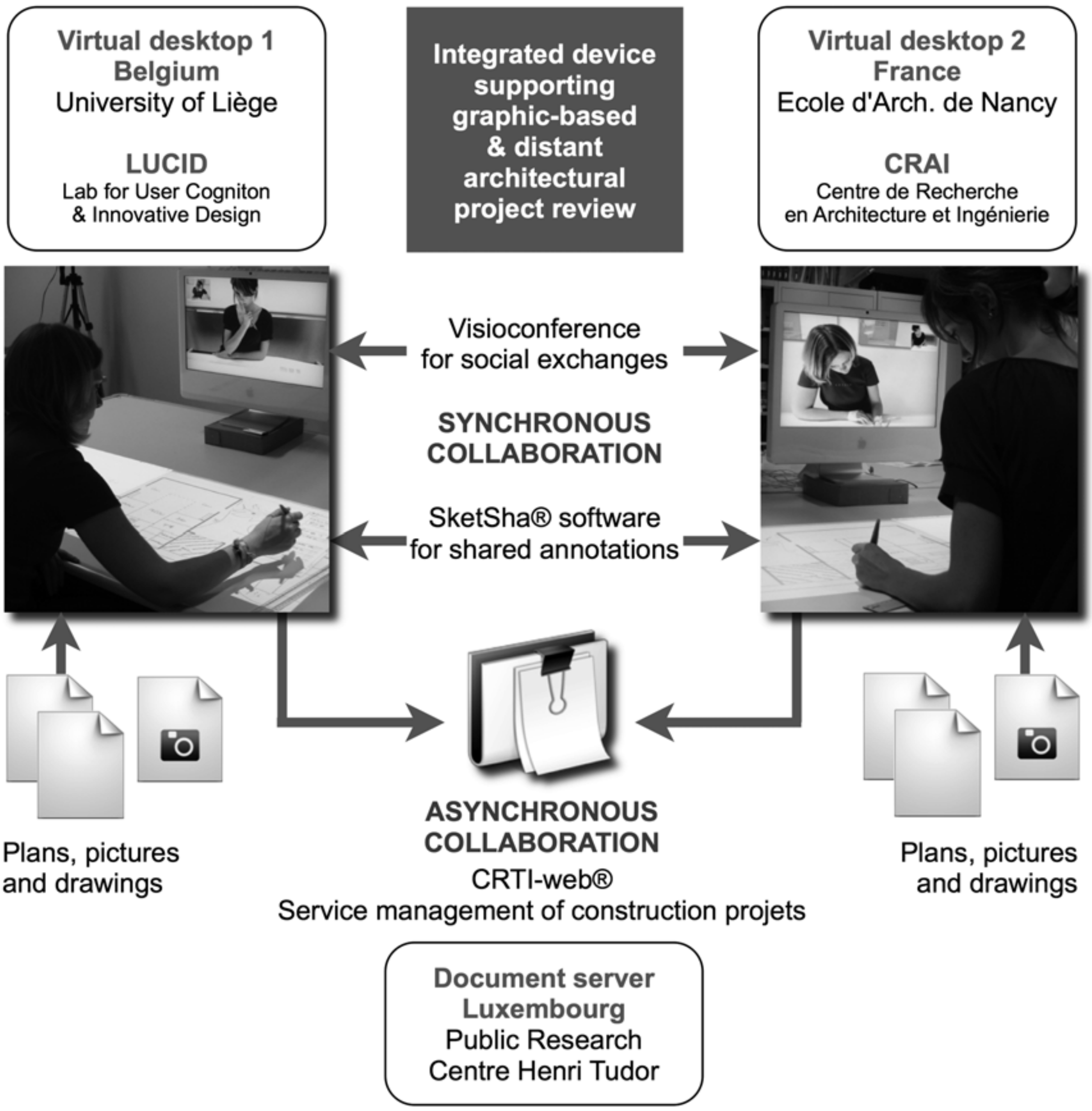

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Digital Collaborative Studio : 4 years of practice.

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1. Context and objectives

For the fourth time this year, the University of Liège and the National school of architecture of Nancy have organized a distant collaborative architectural studio, gathering students in architecture and building engineering from the two institutions. This workshop's assignment has teams of 3 to 5 students (made up of students from the two locations) designing a building (given a set of specification) during 3 months by collaborating remotely. The distant collaboration is supported by several tools: e-mails for asynchronous exchanges, videoconferencing, chat and phone for synchronous collaboration and two original devices : the Virtual Desktop, a collaborative multimodal environment and the CRTI-Web, a bespoke document management system dedicated to architecture

2. Specific tools

The **Virtual Desktop** is a remote workspace environment aiming to emulate, at a distance, the conditions of face-to-face meetings. It comprises an original pen-based device, equipped with a real-time sketch sharing software (SketSha) and completed with a generic videoconferencing system. This environment allows the users to import documents (plans, pictures, sketches,..), to share them remotely and to annotate them in real time with the electronic pen, while conversing and being able to see each other (through the videoconference system).

The **CRTI-Web** is a shared project space, available for all the participants on a Web platform. It allows the project's members to upload the documents that they produce and to share them with the others, tracing their updates and modifications. Moreover it enables also to notify users when a document is available, and to assign tasks, such as validation requests or reaction demands.

3. Modalities

Each year, the schedule consists of (with variations depending on each year's specific logistical constraints): a kickoff face-to-face meeting along with a visit of the project site. The groups are constituted and each participant is assigned a specific role in the group (architecture, interior design, energetic issues, accessibility…). The students thereafter work remotely for about 10 weeks. Weekly synchronous meetings take place in each group using the Virtual Desktop, while asynchronous work is unconstrained and supported by CRTI-Web and usual email exchanges. A final face-to-face presentation in front of the jury concludes the workshop, during which students have to present their design as well as a reflection about their way of collaborating.

4. Results

Overall, the outcomes are very satisfying : the productions are quite complete and sophisticated, the tools and environments work efficiently and the whole collaboration seems to be a positive experience for the students. This workshop also highlights some difficulties linked to the distance: poor social bonds between students and difficulties to work on a real collective design (but rather on different design assembled in a coherent manner). It also highlights some needs and advantages linked to the two specific collaborative environments, which constantly evolve according to those observations.

[Kubicki S., Bignon J-C., Elsen C., Lotz J., Gilles Halin G., & Leclercq P., 2008. Digital Cooperative Studio, Proceedings of ICE'08, 14th International Conference on Concurrent Enterprising, Special session ICT-supported Cooperative Design in Education, University of Nottingham, UK]

Travail collaboratif

Travail collaboratif

Gilles Halin, Sylvain Kubicki, Conrad Boton, Daniel Zignale 152
From collaborative business practices to user's adapted visualization services: towards a usage-centered method dedicated to the AEC sector.
CDVE 2011, Hong-Kong, Chine.

Résumé :
De l'analyse des pratiques collectives métiers au développement de services de visualisation adaptés : vers une méthode centrée usages dédiée au secteur AIC.
La visualisation du contexte de l'activité collective est un enjeu important, particulièrement lorsqu'elle concerne une activité complexe et instable, comme c'est le cas dans le champ de l'architecture, l'ingénierie et la construction (AIC). Dans le but d'assister les projets de conception/construction architecturale, il est important de fournir aux professionnels du secteur des services dits « métiers » (c.à.d. déduits de leurs besoins dans la pratique de leur métier) au travers de vues adaptées à leurs exigences ainsi qu'à leurs usages (outil, environnement). Cet article développe ce concept de « service de visualisation adapté » ainsi qu'une méthode « centrée-usages » pour la conception de ces services pour le domaine AIC.

Conrad Boton, Sylvain Kubicki, Gilles Halin 161
Method to design coordinated multiple views adapted to user's business requirements in 4D collaborative tools in AEC.
IV 2011, Londres, Royaume-Uni.

Résumé :
Méthode pour concevoir des vues multiples coordonnées adaptées aux besoins métiers dans les outils collaboratifs 4D en AIC (Architecture Ingénierie et Construction).
La coordination des vues multiples est devenue un sujet d'étude reconnu dans le domaine de l'Architecture, de l'Ingénierie et de la Construction (AIC) depuis l'apparition et le succès récent des fonctionalités 4D/nD dans les outils de CAO. Afin d'adapter la visualisation pour les besoins « métiers » (c.à.d. déduits de leurs besoins dans la pratique de leur métier) de l'utilisateur dans les outils collaboratifs prenant en charge la 4D, ce papier propose une méthode pour concevoir des vues multiples coordonnées reposant sur l'Ingénierie Dirigée par les Modèles (IDM). Cette méthode permet la description des besoins des utilisateurs en terme de visualisation et la comparaison des différents modes de visualisation. L'objectif est de choisir les modes de visualisation les plus appropriés aux besoins métiers, de leur associer des principes d'interaction et des mécanismes de coordination afin de composer des vues multiples coordonnés adaptés aux besoins métiers de chacun des acteurs du projet. L'article présente une étude de cas basée sur une revue bibliographique et des entretiens avec des praticiens du secteur de la construction.

Annie Guerriero, Sylvain Kubicki, Gilles Halin 167
Trust-oriented multi-visualization of cooperation context.
IV 2009, Barcelone, Espagne.

Résumé :
Multi-visualisation orientée confiance d'un contexte de coopération.
L'activité de construction d'un bâtiment est incertain par nature à cause de ses spécificités (hétérogénéité des intervenants, équipes éphémères, etc.) et particulièrement, parce qu'elle correspond à un mode de production sur « site » qui est conditionné par un contexte variant d'un chantier à un autre. Ainsi la gestion du chantier est essentielle pour garantir une bonne progression de l'activité de construction. Par ailleurs, la confiance est centrale dans ce type d'activité afin de surmonter l'incertitude inhérente. Par conséquent nous suggérons de mettre en relation les outils d'assistance à la coordination avec la notion de confiance. Cet article propose une représentation de la confiance attachée à la progression de l'activité pour assister la gestion de chantier et exploiter cette représentation pour guider la navigation de l'utilisateur dans un environnement multi-vues. Le papier décris la méthode permettant la mesure de la confiance et sa mise en œuvre dans un prototype.

From collaborative business practices to user's adapted visualization services: towards a usage-centered method dedicated to the AEC sector

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Abstract. Visualization of the cooperation context is an important issue, especially when applied to complex and unstable collective activities, as it is the case in the field of Architecture, Engineering and Construction (AEC). With the aim of assisting cooperative construction projects it is important to propose business services and user views adapted to user's business requirements. This paper presents the concept of "adapted visualization service" and a usage-centered method that enables to design visualization services adapted to actor's business needs.

Keywords: collaborative practice, visualization services, adapted visualization, usage-centered method, cooperative context, business requirement.

1 Introduction

Service-oriented groupware systems supporting the cooperative activities are emerging. They propose IT services that can be used by all the actors during projects of a significant size. Most of these 'large projects' use this type of platform to improve communication between stakeholders. The organization of the actors involved in these projects tends to make uniform the methods of work and the resources management. In most cases, "custom-made" software solutions are implemented and used efficiently in the framework of these contexts of durable cooperation between organizations. However such standardized methods are not common in Architecture, Engineering and Construction (AEC) industry [1].

Indeed, AEC projects involve temporarily teams of heterogeneous actors (architects, engineers, contractors, etc.) able to respond to the customer's requirements. Each of these heterogeneous firms has its own internal processes, methods and IT infrastructures. Then cooperative activities in the AEC sector are different from one project to another. Each project generates its own cooperative context, i.e. a set of specific stakeholders, particular processes or communication practices.

Visualization of such cooperation context is an important issue, especially when applied to complex and unstable collective activities, as it is the case in the field of AEC. In order to consolidate the cooperation context, it is important to propose business services and user views adapted to user's business requirements. Therefore, the concept of "business visualization service" is developed in order to take into account such requirements in service systems developments. Our main hypothesis is that visualization in services systems user interfaces have to fit actors' usages. Indeed, actors have specific practices according to their roles in an activity.

This approach suggests a usage-centered method to design Adapted Visualization Services (AVS), describing collaborative practices, usages, and visualization services, and the relationships between their concepts. This method, inspired from UI design methods from software engineering [2] or HCI domains [3], integrates an innovative visualization service design process which guides the AVS configuration according to the identification of a set of collaborative practices needed in a collaborative project.

2 Towards a method to design adapted visualization services

To design adapted visualization services for each actor business needs in a collaborative tool, a method based on a 4-steps process is proposed (Fig. 1). Each step of the method is supported by appropriate meta-models. Indeed, Model Driven Engineering approach recommends the use of meta-models to define domain languages, thus each model has to be conformed to its meta-model [4,5].

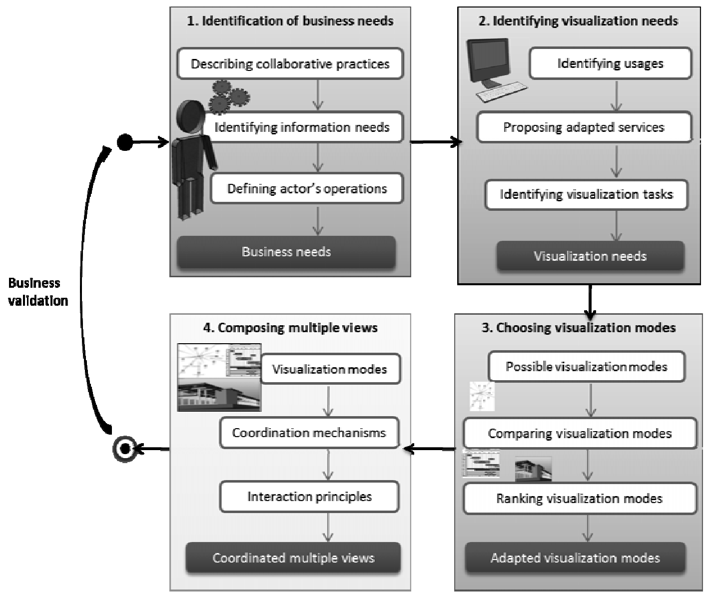


Fig. 1. Method to compose adapted visualization techniques

2.1 Identifying actor's business needs (Step 1)

The first step identifies the business needs of actors. This consists in formalizing the collaborative practices and decomposing them in more role-specific practices. Knowing these practices helps to better define the business needs. Collaborative Practices (CPs) are defined as the behaviors of groups of actors (at least two) working together in various organizational situations according to business objectives [6]. These objectives are related to the AEC project requirements. Then, such CPs can be repeatable until the objectives achievement. CPs are decomposed focusing on each actor and defining their own practices: the Individual Practices (IPs). Each IP is defined by a business individual goal and composed of several Operations. Finally, usages - defined by an instrumental nature - confront actors to specific tools which support their operations. Each usage has its own context depending on the device used, its usual localization, or its frequency... (Fig 2).

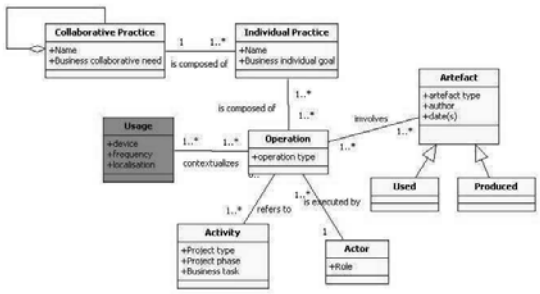


Fig. 2. Usage Meta-Model (UMM)

The Usage Meta-Model (UMM) characterizes this description. The concept of usage defines the context of execution of business operations (device used, localization, frequency...). The aim is the identification of standards operations performed in business activities, like "share", "consult", "create", "modify", "require"…One can see in the UMM which actors are responsible of each operation. The actors are defined by their business role in the project. The UMM also precises which artefacts are used or produced (i.e. documents like plans, meeting reports but also objects like materials or not formalized artefacts like reactions or validations). These artefacts can be characterized by their author(s) and some related dates (date of creation, modification, sharing…). Finally, operations are related to project types, phases and tasks. All these elements describe the business specificities that have to be considered.

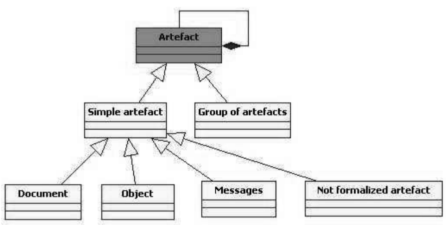


Fig. 3. The artifact concept characterized in the cooperative context meta-model

The particularity of this approach is that the business-related concepts (actors, artifacts, activities) are already identified in a domain model, i.e. the Cooperative Context Meta-Model (CCMM) of a construction project [5]. There is no need to redefine them. A part of this CCMM illustrated in fig.3 represents how business-related concepts (here the concept of artefact) are described.

Based on the meta-models defined, each collaborative situation can be described accurately. The second step of the method consists of defining visualization tasks for each role-specific operations and corresponding usages identified in a CP.

2.2 Identifying visualization needs (step 2)

When the collaborative practices are identified and decomposed into standard operations with their related usages, the corresponding visualization needs can be identified. Indeed, this is very important in order to adapt visualization services that will be provided to support actor's needs. In our specific context, visualization needs are the visualization tasks and interactions that a user will need to perform in front of a computer-supported tool. Visualization tasks are the "analytic and exploratory tasks that he might need or want to perform on the data" [6]. A visualization tasks meta-model is proposed (Fig 4), relying on [9].

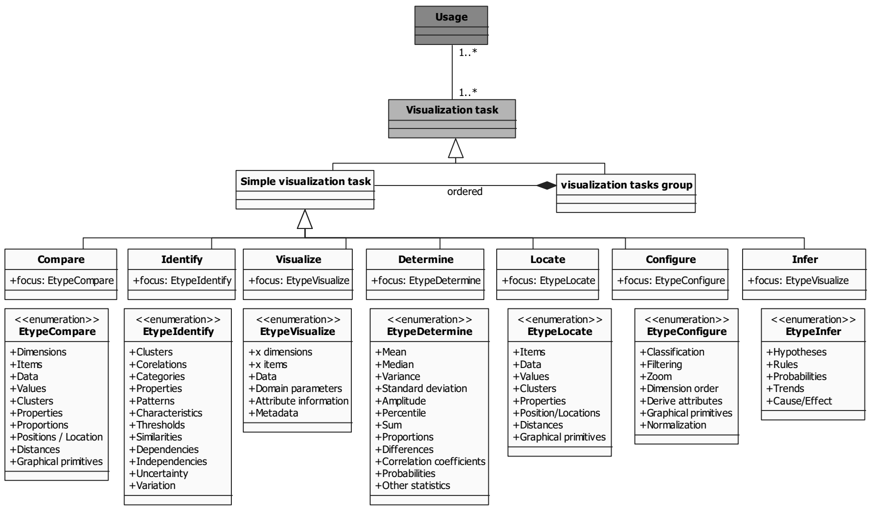


Fig. 4. User's visualization tasks meta-model.

2.3 Choosing adapted visualization modes (step 3)

As one knows, many visualization techniques can exist to represent the same information. For example, both Gantt chart and PERT network can depict an activity planning. Whenever possible, we will appeal to business view. "Business views" are the visualization modes that practitioners use in their daily work. The purpose of this step is to choose the most adapted views for given usages. Firstly, it is useful to describe possible visualization modes in order to compare them. To this end, a business view meta-model is proposed (Fig. 5). That will help in describing possible business views according to the same formalism.

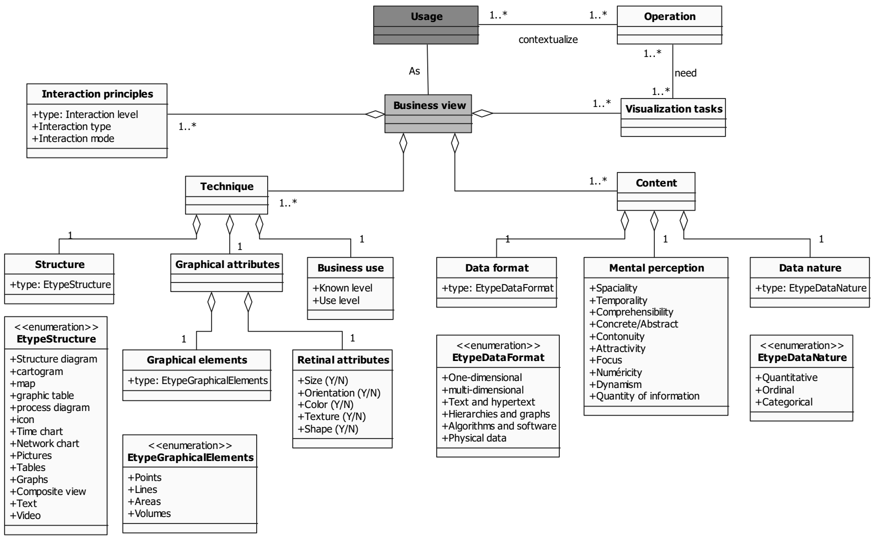


Fig. 5. Business view meta-model

But even if this description is necessary, it is not sufficient to choose the most adapted among the possible visualization modes. It is then useful to be able to rank them. A ranking system is proposed and enables to attribute a score for each business view.

This *adaptation score* (*As*) is calculated for each actor and each Usage with the formula below. The business view properties (fig.5) are used as criteria. The Meta-Model characterized these criteria and the matching between Business view and Usage through the *As*.

$$As = \frac{\sum_{i=1}^{n} Nc_i}{n} \quad \text{with} \quad Nc_i = \frac{\sum_{j=1}^{m} P_j}{m}$$

As is the average of the *Nci* and n is the number of criteria while m is the number of proprieties for a criterion *i*. The score (Nc_i) of a criterion i is then the average of its properties relevance (P_j) scores according to a visualization requirement. The visualization requirement is both an information need and a need for visualization tasks. The properties relevance scores (P_j) are -1, 0 or 1 depending on whether the property *j* is clearly unsuited, poorly adapted or well suited to the sub-practice. Each Nc_ivalue may vary between -1 and 1.

2.4 Composing adapted visualization services (step 4)

When the most adapted visualization modes are chosen for each business need of an actor, it is then possible to put them together in order to propose coordinated multiple views. An Adapted Visualization Service (AVS) is a set of adapted services proposed with appropriate coordinated multiple views to display information. So, for each business role, the appropriate coordination mechanisms and interaction principles will be determined. Exploration techniques and coordination control are two of the fundamental areas of coordinated and multiple views [8]. The utility of multiple coordinated views comes from users' ability to express multidimensional queries through simple forms of interaction [11]. To compose coordinated views, the 2x3 taxonomy of multiple window coordination from [11] and the state of the art proposed by [8] are some interesting starting points. So, relied on these literature references and our specific needs, work is ongoing in order to propose an adapted visualization service meta-model.

3 Case study

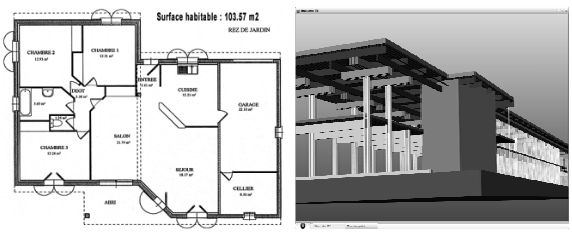
Eleven Collaborative Practices [12] were distinguished during the principal phases of a construction project realization (preparation, design and execution phases). This distinction has emerged through an analysis of project descriptions and brainstorming with professionals. Depending on the context, each Collaborative Practice can be specified and divided in sub-practices. In this case study the CP related to the "execution preparation and management" is considered. This CP gathers site scheduling, material management, feedback formulation from contractors, etc. Attention will particularly be focused on the "site scheduling" collaborative sub-practice.

Table 1 considers both step 1 and 2 of our method. It represents the "site scheduling" collaborative sub-practice, decomposed in Individual Practices and Operations with their related Usages. Then, it defines corresponding visualization tasks.

When visualization tasks are known, possible visualization techniques comparison is needed in order to choose the most adapted one according to these needs. In instance, for the individual practice "Activities sequencing", actor need to visualize the dates, the activities durations and a building representation. The building representation could be a 2D plan or a 3D representation (Fig. 6).

Table 1. Site scheduling collaborative practice and related usages and visualization tasks

Collaborative practice	Individual practices	Operations	Usages	Visualization tasks
Collaborative site scheduling	Building elements listing	Consult elements pre-list	- *Architect consults documents from his office* - *Architect edits listings from his office* - *Architect shares listings information from his office*	*Visualize* (focus: *data*)
		Look for appropriate elements		*Locate* (focus: *items*)
		Create elements listing		*Configure* (focus: *classification*)
	Activities definition	Consult activities pre-list	- *Supervisor consults documents and items from his office* - *Supervisor edits listings from his office* - *Supervisor shares listings information from his office*	*Visualize* (focus: *data*)
		Consult building elements		*Locate* (focus: *items*)
		Look for appropriate activities		*Identify* (focus: *correlations*)
		Create activities listing		*Configure* (focus: *classification*)
	Activities duration estimation	Consult activities	- *Sub-contractor consults items from his office* - *Sub-contractor draws conclusions from his office* - *Sub-contractor shares activities duration from his office*	*Visualize* (focus: *data*)
		Understand activities consistency		*Configure* (focus: *filtering*) *Determine* (focus: *means*)
		Estimate activities duration		*Infer* (focus: *hypotheses*)
	Activities sequencing	Consult activities and durations	- *Contractor consults documents from his office* - *Contractor looks for information from his office* - *Contractor edits planning information from his office* - *Contractor shares conflicts and dates information from his office*	*Visualize* (focus: *data*)
		Study relationships and dependencies among activities		*Identify* (focus: *correlations*) *Identify* (focus: *dependencies*)
		Verify conflicts		*Infer* (focus: *trends*)
		Associate start/end dates		*Configure* (focus: *classification*)
		Define site planning		*Configure* (focus: *normalization*)
	Schedule development	Consult activities listing	- *Supervisor consults documents and items from his office* - *Supervisor edits planning information from his office* - *Supervisor shares project plan information from his office*	*Visualize* (focus: *data*)
		Consult actors listing		*Visualize* (focus: *data*)
		Associate actors and activities		*Identify* (focus: *correlations*)
		Include planning		*Infer* (focus: *trends*)
		Realize project plan		*Configure* (focus: *classification*)



2D plan 3D representation

Fig. 6. Proposal for building representation modes

After describing them, their adaptation score (As) can be calculated following the step 3. Results for the present case study are represented in table 2. The score in this table are not validated yet and future works will focus on it and, more generally, on practitioner's evaluation of business views according to their experience. However, the example in table 2 can show that the 3D representation is more adapted than the 2D plan.

Table 2. Calculation of visualization modes adaptation score

Criteria	Proprieties	3D rep.	2D plan
Technique	Structure	0	-1
	Graphical elements	1	0
	Retinal attributes	1	0
	Business use	0	1
	Nc_1	**0,5**	**0**
Content	Data Format	1	1
	Mental perception	0	-1
	Data nature	0	-1
	Nc_2	**0,33**	**-0,33**
Interaction principles	Interaction level	1	-1
	Interaction type	0	-1
	Nc_3	**0,5**	**-1**
Visualization tasks	Visualisation tasks	1	0
	Nc_4	**1**	**0**
	As	**0,58**	**- 0,33**

Same work for each other usages will lead to know all the needed adapted visualization modes for each actor. In the last step, interactions and coordination mechanism will be associated in order to build adapted visualization services for all the actors.

4 Conclusion

The paper presents a usage-centered method that enables to design "Adapted Visualization Services". It considers actor's business Usages related to the "Collaborative Practices" (CP) in which they are involved. The models that support each step are presented and a formula is proposed to rank visualization modes. This method is illustrated through a case study related to the site scheduling business Collaborative Practice.

In the future, focus will be on the fourth step of the method which is still in an early stage of development. It will be particularly formalized by proposing a coordinated multiple views meta-model. The advantage of this model-driven approach is the possibility to support it by software tools. The design of such tools that will support the method will allow us to 1) extend it to other case studies and 2) confront it to professionals in order to validate both the method and the final propositions in terms of Visualization Modes. The possibility to represent graphically the CPs through diagrams is explored using the Eclipse environment and particularly the GMF framework (Graphical Modeling Framework).

Acknowledgment:

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Method to design coordinated multiple views adapted to user's business requirements in 4D collaborative tools in AEC

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Abstract

The issue of multiple views coordination became more and more challenging in the architecture, engineering and construction (AEC) field since the apparition and the increasing success of 4D/nD CAD. In order to adapt visualization to user's business requirements in 4D-supported collaborative tools, this paper propose a method to design coordinated multiple views based on Model-Driven Engineering (MDE).The method enables user's visualization needs description, visualization modes comparison. The aim is to choose appropriate visualization modes business needs, to associate interaction principles and coordination mechanisms in order to compose coordinated multiple views adapted to actor's business needs. The paper presents a case study based on literature review and interviews with construction sector practitioners.

Keywords--- **AEC, 4D CAD, Coordinated Multiple Views, Visualization modeling, Model-Driven Engineering, CSCW, Business views**.

1. Introduction

Coordinated multiple views (CMV) are increasingly used since their introduction and several studies have been conducted to improve their use [1-4]. But in some complex and highly collaborative fields like architecture, engineering and construction (AEC), the use of CMV deserves special attention. A major issue concerns the adaptation of views to user's business requirements in such fields. Indeed, in the construction sector, each actor usually has a specific role which follows from the partner's primary business field. It usually results in specific views used for representing building-related information [5]. Moreover, several representation modes can represent the same concepts and actors choose one or the other of these modes according to their specific needs related to the tasks they have to achieve. Then, adapting visualization to user's business needs in collaborative work supporting tools implies being able to choose the best visualization modes and to associate to them the most appropriate interaction and coordination mechanisms in order to design adapted multiple views.

Since the increasingly growing success of simulation tools based on 4D CAD (that associates a 3D view and a temporal view), the issue of multiple views composition and coordination becomes more and more important in the construction sector.

The following work relies both on Information Visualization and Human-Computer Interaction theories. It proposes a method to compose and coordinate adapted multiple views for users of 4D-based collaborative tools in construction projects.

2. 4D multiple views issue in AEC sector

The concept "multiple views" in general describes visualizations where multiple windows are used to represent data [6]. So, "a multiple view system uses two or more distinct views to support the investigation of a single conceptual entity" [1]. Many current windowing environments treat windows as independent and isolated, and users have to manipulate individually one window at a time, even when some contents or tasks are common among the windows [7]. But we will use "coordinated multiple views" when operations on the views are coordinated [6]. In this case, the same or different portions of the data can be displayed by windows and these windows can be tightly coordinated in "a variety of ways such that interacting with one component causes meaningful effects in others" [2]. So, coordination ensures that changes in one window are propagated to all other views keeping the analyzed data consistent [8]. In designing user interfaces, multiple window coordination is more and more effective [9] and CMV strategies are gradually more used in visualization and interfaces [7].

An important capability enhanced by coordination in Information Visualization is about flexibility regarding data; selection of a type of visualization mode for a given set of data; and coordination characteristics definition [8].

The Architecture, Engineering and Construction (AEC) industry is characterized by "its loose organization of the different participants that each perform a specific role in a building project and have a specific view on the building project data" [5]. So, if the whole lifecycle of construction project can be covered by computer visualization usage [10], it has to support the highly collaborative aspect of the project. Indeed, in the sector, each discipline has to process a large amount of information related to the representation of a design object between disciplines. And from a stage to another, actors need to represent and share different kinds of information with various levels of abstraction [11]. Moreover, as we said, in the AEC field, several visualization modes can represent the same concept and actors choose one or the other of these modes according to their specific needs related to the task they have to perform. Indeed, cooperation assistance tools have to integrate interfaces that take into account the existence and the specificity of "business-views". "Business views" are the visualization modes that practitioners use in their daily work [12]. For example, tasks planning may be represented by a Gantt chart or by a PERT network and building elements can be depicted with a 3D model or a 2D plan. So to support the collaborative aspect of AEC projects, multiple views systems have to be adapted to users' business requirements and views have to be chosen wisely.

With the rise of 4D CAD as a reference simulation tool in the sector, the issue of coordination of multiple views becomes more important. 4D CAD consists in linking a 3D view of the building to a time view (works planning) to simulate the building construction over the time. Such visualizations respond to the four design rules related to diversity, complementarity, parsimony, and decomposition proposed by [1] about when to use multiple views.

The use of 4D simulation tools has a real impact in construction projects ([13]; [14]) and more recently, [15] showed that the collaborative use of 4D CAD is particularly useful during the pre-construction phase for comparing the constructability of working methods, for visually identifying conflicts and clashes (overlaps), and as visual tool for contractors, subcontractors and suppliers to discuss and to plan project progress. But in the framework of this collaborative use, the adaptation of 4D multi-views to users' business requirements remains a challenging issue since the classical view (3D + Gantt) usually proposed to all practitioners in most of the current 4D tools seems not suiting the needs of every actors and situations of use.

In the next section, we propose a method aiming at designing adapted business multiple views for 4D collaborative tools in AEC sector.

3. Method to design adapted 4D coordinated and multiple views

3.1. The method's steps

We propose a multi-steps method to adapt visualization to actor's business needs in collaborative work supporting tools.

- The first step identifies the business needs of actors. This consists in formalizing the collaborative practices in order to identify the sub-practices performed by the different involved actors. Knowing these sub-practices helps to better define the business needs.
- In the framework of these collaborative practices, actors use groupware to perform their business activities. During these activities, we can identify specific usages that we have to understand and describe. The purpose of the second step is to determine the visualization needs for each actor. This step also highlights the actor's interactions and visualization tasks related to business practices. At this stage we use the taxonomy proposed by [16] to describe such visualization tasks with a single and accurate formalism (Fig. 2).

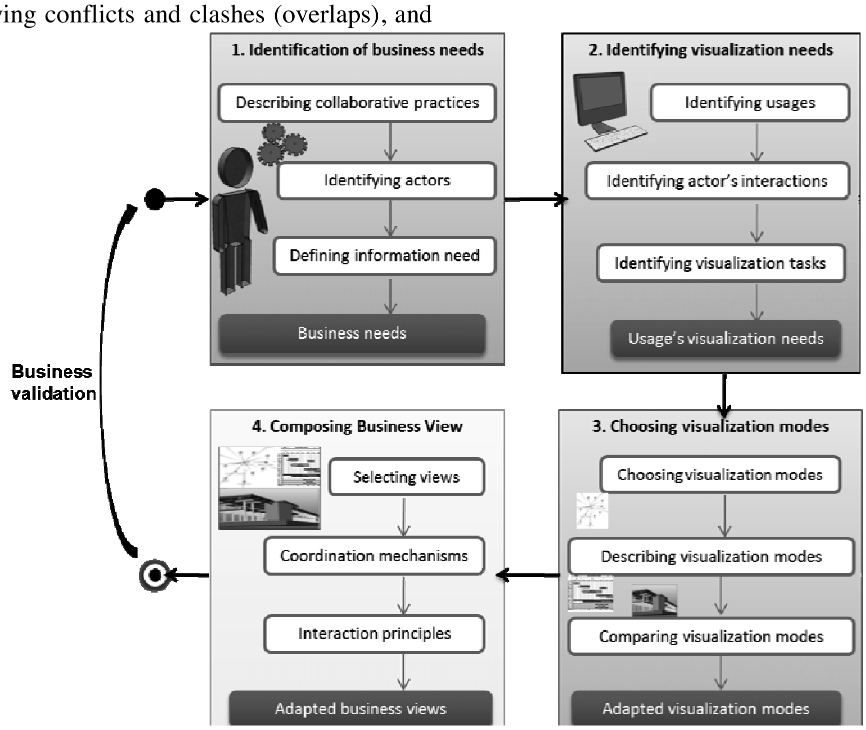


Figure 1: Method to compose business view

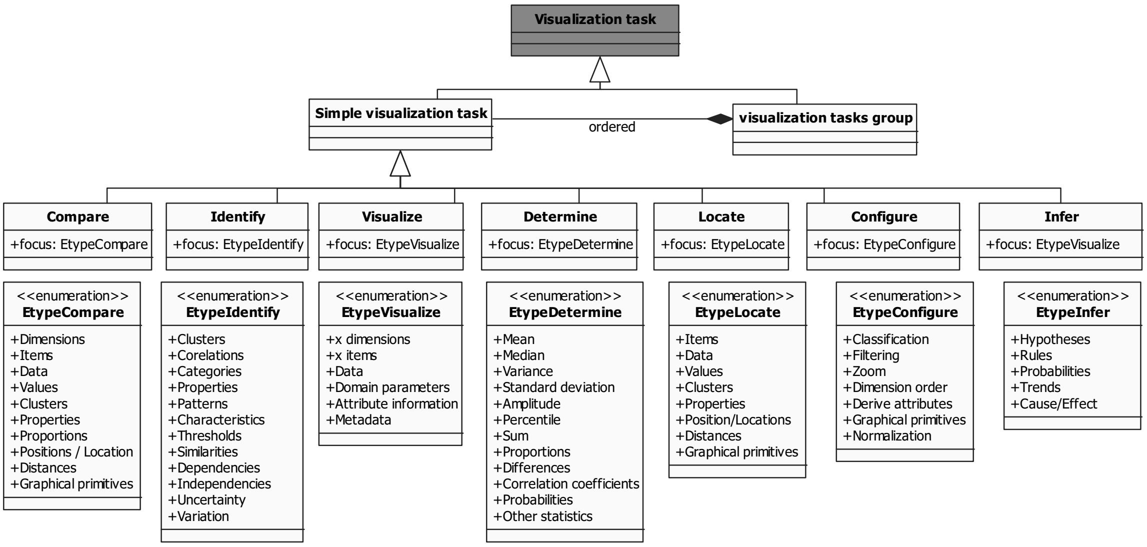


Figure 2: User's visualization tasks metamodel

- After visualization needs known, it is then possible to compare the possible visualization modes in order to choose the most appropriate in relation to the expressed needs. This is the subject of the third step in which the visualization modes are described and compared.
- When appropriate modes are selected for each actor, one can select those that may be composed together to form multiple coordinated views. To this end, it is important to study the coordination mechanisms and the interaction principles associated with the visualization modes (fourth step). At the end of this step, adapted business views are composed for each actor.

These views will then be validated to ensure that the propositions respond effectively to the expressed business needs. Fig. 1 depicts the steps of the method.

Model Driven Engineering (MDE) approach recommends the use of metamodels to define domain languages, so each model has to conform to its metamodel. In order to model visualization modes and to choose the most adapted ones, we propose to adapt and use the business view metamodel described in [17].

3.2. Formula for visualization modes ranking

We are working on a scoring system that would rank visualization modes according to usage needs. By assessing the criteria (technique, content, interaction principle, visualization tasks, etc.) an *adaptation score* (As) should be assigned to each visualization mode. This score is calculated for each actor and each sub-practice with the formula below. So, the relevance of a criterion is related to the information needs and to the visualization tasks.

$$As = \frac{\sum_{i=1}^{n} Nc_i}{n}$$

The score (Nc_i) of a criterion *i* is then the sum of its properties relevance (P_j) scores according to a visualization requirement. The visualization requirement is both an information need and a need for visualization tasks. Nc may vary between -1 and 1.

3.5. Composing coordinated multiple views

Exploration techniques and coordination control are two of the fundamental areas of coordinated and multiple views [6]. The utility of multiple coordinated views comes from users' ability to express multidimensional queries through simple forms of interaction [18]. To compose coordinated views, we use the eight guidelines proposed by [1] for the design of multiple view systems and the 2x3 taxonomy of multiple window coordination from [7]. Relied on these references and the state of the art proposed by [6], we are working to propose a metamodel of multi-views composition. This metamodel will take into account notions related to multiple views generation, exploration techniques, coordination and control, human interface and usability and perception.

4. Case study

We consider a case study related to site preparation collaborative context and apply our method to a specific collaborative practice: "Collaborative site scheduling". The case study is established on the basis of literature review and various interviews conducted. Indeed, we interviewed six practitioners with different roles from Luxembourg construction sector, in order to understand their common activities in the pre-construction framework and to better formalize the applied issue of this work. In this realistic case study we assume that in a given situation some actors are responsible for each of the sub-practices shown on table 1.

4.1. Step 1: Identifying business needs

For the case study, we show in table 1 the result of the first step. The sub-practices which will be performed are known such as the associated responsible actors. The information needs are also identified. We see that to list building elements, the architect needs to visualize the building representation and a pre-list of building elements. The supervisor needs a work breakdown structure (WBS) and a pre-list of construction activities, to define activities and the activities planning to develop the schedule. To estimate activities duration, sub-contractors will need the description on these activities while the contactor will have to visualize dates, activities durations and a building representation to create the activities sequences.

Sub-practices	Responsible actors	Information need
Building elements listing	Architect	Pre-list of building elements, building representation
Activities definition	Supervisor	WBS, pre-list of construction activities
Activities duration estimation	Sub-contractors	Activities description
Activities sequencing	Contractor	Dates, activities durations, building representation
Schedule development	Supervisor	Activities planning

Table 1: collaborative site scheduling practice

But this is not sufficient enough to choose appropriate visualization modes. It is necessary to add the visualization tasks to be sure to take into account the actor's visualization needs.

4.2. Step 2: Identifying visualization tasks

After understanding the context of the CP, the method's step 2 aims at identifying the visualization tasks the actors will have to perform. For this, sub-practices are divided into elementary usages that will call for specific visualization tasks. The visualization tasks model will help us in this description as shown in table 2.

We see that to list building elements, as visualization tasks, architect will need to *visualize data*, *locate items*, and *configure classifications*. The activities definition will lead to *visualize data, locate items, identify correlation* and *configure classification*. To estimate activities duration, sub-contractors have to *visualize data*, *configure filtering*, *determine means* and *infer hypotheses*. For activities sequencing, contractor will *visualize data, identify correlations and dependencies, infer trends, configure classifications* and *configure normalization*. The schedule development requires visualizing data, identifying correlations, inferring trends and configuring classification.

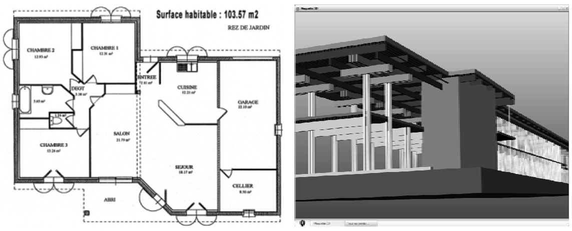
Sub-practices	Elementary usages	Visualization tasks
Building elements listing	Consult elements pre-list	*Visualize* (focus: *data*)
	Find appropriate elements	*Locate* (focus: *items*)
	Create elements listing	*Configure* (focus: *classification*)
Activities definition	Consult activities pre-list	*Visualize* (focus: *data*)
	Consult building elements	*Locate* (focus: *items*)
	Identify appropriate activities	*Identify* (focus: *correlations*)
	Create activities listing	*Configure* (focus: *classification*)
Activities duration estimation	Consult activities	*Visualize* (focus: *data*)
	Understand activities consistency	*Configure* (focus: *filtering*) *Determine* (focus: *means*)
	Estimate activities duration	*Infer* (focus: *hypotheses*)
Activities sequencing	Consult activities and durations	*Visualize* (focus: *data*)
	Study relationships and dependencies among activities	*Identify* (focus: *correlations*) *Identify* (focus: *dependencies*)
	Verify conflicts	*Infer* (focus: *trends*)
	Associate start/end dates	*Configure* (focus: *classification*)
	Define site planning	*Configure* (focus: *normalization*)
Schedule development	Consult activities listing	*Visualize* (focus: *data*)
	Consult actors listing	*Visualize* (focus: *data*)
	Associate actors and activities	*Identify* (focus: *correlations*)
	Include planning	*Infer* (focus: *trends*)
	Realize project plan	*Configure* (focus: *classification*)

Table 2: Actors' visualization tasks

After this step, the exact information that actors need to visualize and their visualization tasks are known. For each information need, many visualization modes may be possible. It is necessary to compare them in order to choose the best adapted ones according to actor's visualization tasks.

4.3. Step 3: Choosing adapted visualization modes

In this step, the business view metamodel (ref section) is used to describe the possible visualization modes for every expressed visualization need. In instance, for the sub-practice "Activities sequencing", actor need to visualize the dates, the activities durations and a building representation. The building representation could be a 2D plan or a 3D representation (Fig. 4). It is then necessary to describe these two visualization modes in order to compare them.



2D plan 3D representation

Figure 3: Some visualization modes

Table 3 shows a comparison between these two visualization modes that could be used to represent building elements. For example, 3D representation is easy to understand and more attractive than 2D plan. More interactions are possible with 3D representations than with 2D plan. At the contrary, 2D representation is widely known and used compared to 3D.

	3D representation	2D plan
Technique structure	3D	2D
Graphical elements	Volumes	Lines, surfaces
Retinal attributes	Size, Shape, Colors, Form	Size, texture, Form
Known level	Very known	Very known
Business use level	Quite used	Very used
Data Nature	Physical Data	Physical data
Data spatiality	Spatial	Spatial
Temporality	No temporal	No temporal
Comprehensibility	Easy	Difficult
Concrete-Abstract	Concrete	Abstract
Attractivity	Attractive	Less attractive
Focus	Emphasizes whole	Emphasizes parts
Numericity	Non numeric	Non numeric
Dynamism	Static	Static
Possible interactions	Interactive zoom, Dynamic projection, Interactive deformation, Link&Brush	Interactive zoom, Interactive filtering, Link&Brush

Table 3: Visualization modes description

Using the adaptation score formula (table 4), we can establish that 3D representation is better suiting this sub-practice. The score in Table 4 are not validated yet and future works will focus on it and, more generally, on practitioner's evaluation of business views according to our criteria and their experience. Same work for each other sub-practices will lead to know which visualization modes are appropriate. So, for each actor, all visualization modes needed to achieve his usage are known.

Criteria	Proprieties	3D rep.	2D plan
Technique	Structure	0	-1
	Graphical elements	1	0
	Retinal attributes	1	0
	Business use	0	1
	Nc_1	**0,5**	**0**
Content	Data Format	1	1
	Mental perception	0	-1
	Data nature	0	-1
	Nc_2	**0,33**	**-0,33**
Interaction principles	Interaction level	1	-1
	Interaction type	0	-1
	Nc_3	**0,5**	**-1**
Visualization tasks	Visualization tasks	1	0
	Nc_4	**1**	**0**
	As	**0,58**	**- 0,33**

Table 4: Visualization modes adaptation scores

4.4. Step 4: Composing adapted business multi-visualization

After selecting adapted visualization modes, a 4D tool designer would have to make sure that chosen views are compatible. This is the aim of the step 4, and we are still working on it. We will associate appropriate exploration techniques and coordination mechanism according to the needs of each actor. That will lead to a relevant collaborative 4D tool with adapted human interfaces. For example, within the case study, the resulting multiple views could be a "3D+Gantt" visualization for the architect, a "zoomed 3D+Gantt" view with a focus on zoom for contractors and subcontractors, and a "3D + Pert" view for supervisor.

We are still working to improve this step of the method, in order to have better 4D multiple views guidelines or patterns to support it.

Conclusions

The paper presents a method to design coordinated multiple views for 4D-based collaborative tools in order to adapt visualization to user's business needs. The metamodels that support the method are also presented and a case study showed how to use these method and models.

Future works will consolidate the method and a tool will be developed to support it. Both the tool and the method will be validated through confronting it to real business situations.

Acknowledgements

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Trust-oriented multi-visualization of cooperation context

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Abstract

The building construction activity is uncertain by nature because of its specificities (e.g. heterogeneous stakeholders, ephemeral teams, etc.) and particularly, because it corresponds to a particular mode of production "on site" and it is submitted to variable conditions. So the construction management is essential to warrantee the good progress of the construction activity. Moreover, trust is central in this type of activity to surmount the uncertainty. Therefore we suggest making a connection between the coordination assistance tool and the notion of trust. This paper suggests representing trust in the correct progression of the activity to support the construction management and using it to guide user navigation in a multi-visualization environment. It will describe a methodology to measure trust and implement it in a multi-view prototype.

Keywords--- **Trust representation, AEC (Architecture Engineering and Construction), Construction management, Multi-visualization, Cooperation context, Coordination assistance.**

1. Introduction

Trust is an important feature of our everyday lives (Marsh 1994) and particularly when we consider cooperation between actors. It appears as a factor of organizational efficiency and as a substitute of complex and costly contractual forms (Brousseau et al. 1997). Trust has the capacity to surmount the risk linked to the uncertainty of certain environments (Luhmann 1988). Moreover trust may be particularly important for the the ability of workers to self-organize (Rousseau et al. 1998). When trust is present in an organization, the behaviors preserve the interest of the collectivity and limit the opportunism.

The building construction activity describes an uncertain environment where trust is central. The uncertainty results essentially from the production mode on site. The building site is submitted to variable conditions of production (e.g. weather, ground...). Moreover stakeholders are heterogeneous and the team is composed for the duration of the project.

Therefore some dysfunctions can appear. (Tahon 1997) identifies four types of dysfunctions on the building site:

- Dysfunctions related to the documents and their circulation (e.g. problems linked to the update of plans)
- Dysfunctions related to the actors (e.g. mistrust between actors limiting the exchanges)
- Dysfunctions related to the construction activity and its progression (e.g. delayed construction tasks)
- Dysfunctions related to the building elements and their execution (e.g. difficulty to construct on site an element as designed).

In this context the actors' autonomy and their sense of responsibility are essential to warrantee to the quality of the results (Bobroff 1994). Moreover, the construction management becomes essential to ensure the correct progression of the activity (i.e. as expected) and limit the impact of these dysfunctions.

In AEC projects, coordination information is complex and dispersed in numerous views, often not coordinated, i.e. planning charts, meeting reports, plans and so on (Kubicki et al. 2007b). Then a major issue for construction managers remains in consolidating heterogeneous pieces of information in order to appreciate risks.

It is suggested in this article to make a connection between trust and coordination activities. The aim of this research is to use the representation of trust to improve the understanding of the state of a cooperation context. A methodology for trust representation is described. Then it is implemented in a prototype intended for the construction manager and providing multiple views on the cooperation context. Finally some validation elements are presented.

2. Towards a representation of Trust

Literature discusses trust as a particular relationship between actors, organizations, and eventually artifacts (e.g. trust in a website) (Sutcliffe 2006). Trust is largely considered as "*psychological state comprising the intention to accept vulnerability based upon positive expectations of the intentions or behavior of another*" (Rousseau 1998). In the case of our works, trust is considered more globally in the "*correct progression of the activity*" and depends on the four dimensions of the activity context (See Figure 1):

- The progress of the *task*,
- The *actor* (in charge of performing the construction task),
- The *building element* (resulting from the construction task),
- The *document* (required to perform the construction task).

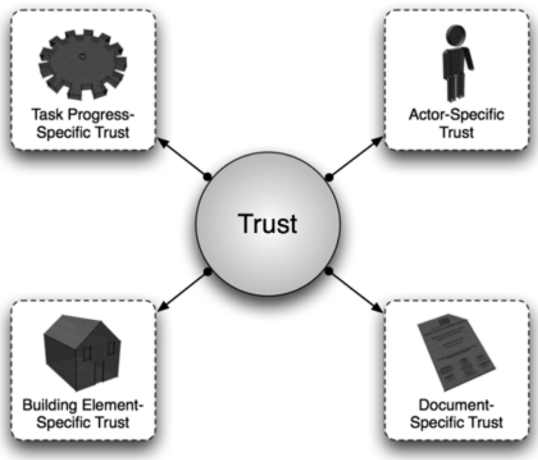

Figure 1 Approach of trust in the correct progression of the activity

The approach is based on five steps inspired about (Chang et al. 2006) (See Figure 2):

1) Modeling the construction activity knowledge,
2) Identifying the aspects which trust relies on,
3) Determining the measurable trust criterion,
4) Defining a method for calculating trust,
5) Implementing trust in a prototype.

The first step relies on anterior research works concerning the study of the particular context of the building construction activity (See (Kubicki 2007b)). Then for each activity dimension, the aspects of trust and the measurable trust criterion have been identified (Step 2 and 3). Table 1 presents an extract of the results.

Activity dimension	Aspect of trust	Trust criterion
Progress of the construction task	Progress	State of the task
		Critical task
	Execution	Number of remarks in the meeting report
	Environment	Minimum forecasted temperature

Table 1 Aspects of trust and trust criterion – Extract of the results

After that, a method for automatically calculating trust on the basis of the value of the trust criterion identified in the previous step has developed. The method is inspired about S.P. Marsh's works (Marsh 1994; Marsh et al. 2005). The method that we suggest relies on the calculation of five trust values:

- The "Global Trust" value corresponds to trust in the correct progression of the construction activity.
- The "Specific Trust" values correspond to trust in the diverse dimensions of the activity:
    - Task Progress-Specific Trust (TP-ST)
    - Actor-Specific Trust (A-ST)
    - Building Element-Specific Trust (BE-ST)
- Document-Specific Trust (D-ST).

Each type of Specific Trust is calculated according to the values of the trust criterion. Then a weighted average of the Specific trust values enables to measure the Global Trust. Each type of trust is associated to a numerical value comprised between -1 (for the weakest

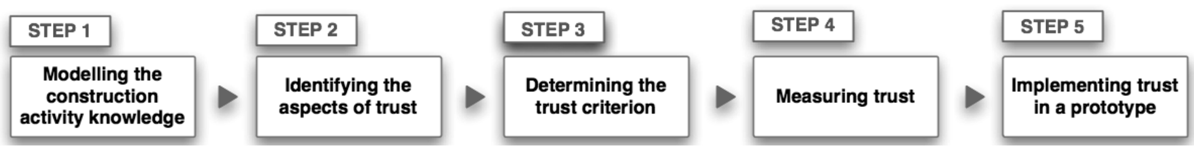

Figure 2 Process for representing trust in the correct progression of the activity

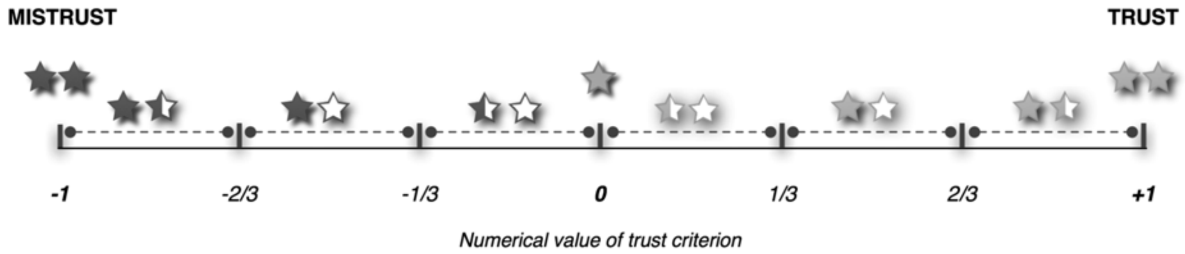

Figure 3 Scale of trust

level of trust) and 1 (for the highest level of trust). (Guerriero et al. 2008) describes in detail the method for calculating trust.

3. Implementing trust in a prototype

The use of the representation of trust in a tool to support the decision is not a new approach. Some e-business services use trust to support the transaction between the vendors and the customers (e.g. eBay[1], Amazon[2]) or to inform about the quality of a product (e.g. Amazon). In the AEC sector some applications relying on the notion of trust are appearing. We can cite for example AEC Performance[3] or Webses (Arslan et al. 2008) allowing the evaluation of the actor's performance. The approach suggested in this article proposes a more global vision about trust in the correct progression of the activity and not only in the actor's performance. It suggests using trust indicators to support the construction manager's activity.

3.1. Representation of trust

In order to propose a visualization of trust, the first stage was to analyze the existing representation on the e-commerce services. Moreover a study of the information visualization has enabled to structure the approach. J. Bertin's works (Bertin 1967) on the semiology of graphics has provided a matrix combining the common task related to the information visualization (i.e. association, selection, order, quantity) and the retinal variables (i.e. size, value, texture, color, orientation, shape) (Spence 2001). We studied diverse combinations of these elements. The principal constraint was to consider the reduced space for the display of the different type of trust indicators and the fact that they had to be placed side by side. In addition, it was important to suggest a representation of trust that could be familiar for the user.

Therefore this analysis led us to consider the symbol of "star" largely used in the e-commerce interfaces (e.g. eBay or Amazon) to represent the user's evaluations. The color and the number of stars appear as the most frequent variables in the interfaces. So the choice is to combine these two variables in order to define a scale of trust (See Figure 3) that associates a graphical value to a numerical value of trust (resulting from the calculation of trust method). This scale suggest two yellow stars for the highest level of trust (numerical value = 1), one grey star for the neutral value of trust (numerical value = 0) and two red stars for the lowest level of trust (numerical value = -1).

3.2. Specific trust and related AEC views

Global and specific trust indicators inform on the state of the progress of the activity. In order to better understand it, the actors make use of "business-views" representing the cooperation context, e.g. meeting reports, planning views and so on. These views manipulate distinct sets of data. But conceptually they could be considered as a whole: a single project cooperation context.

Techniques of multiple window-based visualization (Wang-Baldonado et al. 2000) have demonstrated their efficiency when applied to text collections (Eler et al. 2008), network traffic analysis (Kauer et al. 2008) or software development (Therón et al. 2007). Multi-visualization of the cooperation context based on AEC-specific views has been treated in (Kubicki 2007b) and led to the design of a multi-views prototype "Bat'iViews". This work demonstrated the interest of coordinating multiple views to address AEC coordination problems. But it lacked in facilitating the navigation of its users in complex cooperation contexts.

Based on this experience, trust indicators are envisaged as guiders enabling to facilitate the user's navigation in configurations of multiple views.

An AEC dedicated model-based infrastructure has been introduced in (Kubicki 2007b). It suggests distinguishing between a cooperation context (i.e. domain) model and view modes models. It enables to select appropriate content for visualization but also to manage interactions between views (e.g. relationship between a task in planning view and a remark in meeting report view). Following this modeling approach several

[1] http://www.ebay.com
[2] http://www.amazon.com
[3] http://www.aecperformance.com

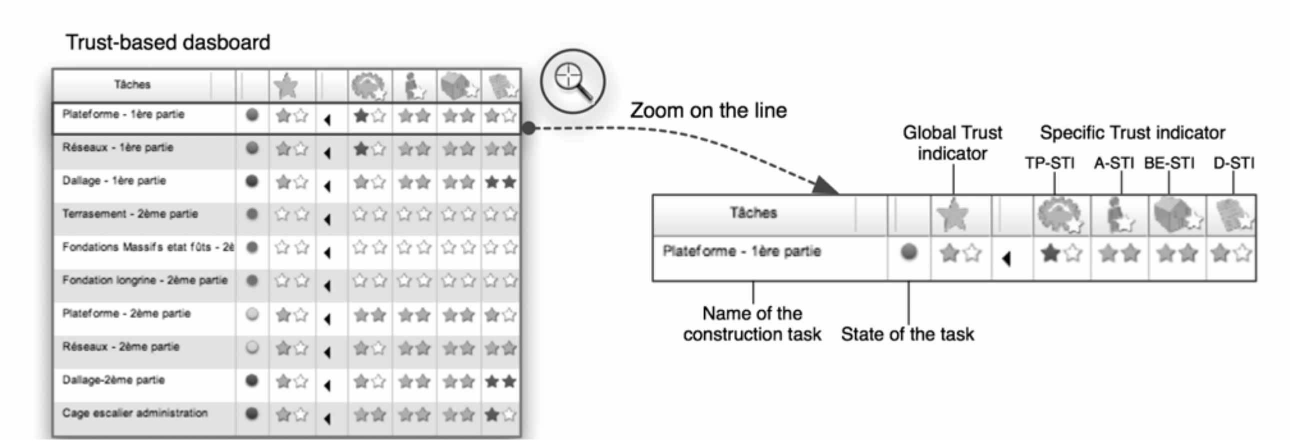

Figure 4 View of the trust-based dashboard

view models have been designed in order to be implemented in a prototype interface.

3.3. Presentation of the Bat'iTrust multi-views interface

Based on these previous works about multi-visualization and the results about trust and its calculation, the Bat'iTrust prototype is developed. The proposition suggests including a view dashboard based on trust in the Bat'iViews prototype (described before) for guiding the navigation in the views of the cooperation context. This approach helps us in going beyond the limits related to navigation capabilities identified in Bat'iViews. The proposition focuses on the construction manager's activity during the construction stage and on the information he has at his disposal to assure the coordination of the construction activity. Bat'iTrust proposes a new way for monitoring the construction activity based on a dashboard centered on the concept of trust.

Bat'iTrust puts into relationship a dashboard view (displaying the construction tasks and their diverse indicators of trust) (See Figure 4) with different configurations of views corresponding to the four dimensions of the activity (i.e. task progress, actor, building element, and document). Each of these configurations is composed of AEC-specific views well adapted to understand a dysfunction occurring on a specific dimension. Let us consider for example the "*task progress*" configuration of views. It is composed of:

- The view "Planning" that illustrates the construction process.
- The view "Remarks in the meeting report" that displays the open remarks which have been identified during the building site meeting.
- The view "Weather forecast" that states the weather forecast on the building site.

In the Bat'iTrust multi-views interface, the dashboard based on trust is the "master" view structuring the user's navigation. It consists in the entry point for the user. The configurations of views are updated in function of the selection in the dashboard and allow the user to better understand the value of the indicators of trust.

Therefore the dashboard based on trust informs the construction manager about the potential dysfunctions on the building site thanks to the trust indicators. When the user selects a specific trust indicator (i.e. TP-STI, A-STI, BE-STI, D-STI), Bat'iTrust returns the appropriate arrangement of views established in order to provide the pieces of information necessary to understand the nature of the problems potentially detected. For example (See Figure 5), when the user selects a building element – specific trust indicator, Bat'iTrust provides a specific configuration of views highlighting the pieces of information related to the construction task under consideration:

- The view "3D model" highlights the building element resulting from the construction task under consideration.
- The view "Description of the building element' displays the specifications of the building element.
- The view "Budget monitoring" displays information related to the budget of the building element (i.e. cost, cost overrun…).

The Bat'iTrust prototype relies on SOA architecture. It consists in a RIA (Rich Internet Application) application implemented with the Flex technology (Adobe) and a set of business services implemented on the basis of the REST technology (Richardson et al. 2007). At the moment, only the data coming from three applications can be used: a task management tool, a meeting report management tool and a document exchange management tool (Kubicki et al. 2007a). Therefore, some applications have still to be developed to cover all the cooperation context dimensions and then to allow the automatic calculation of trust indicators.

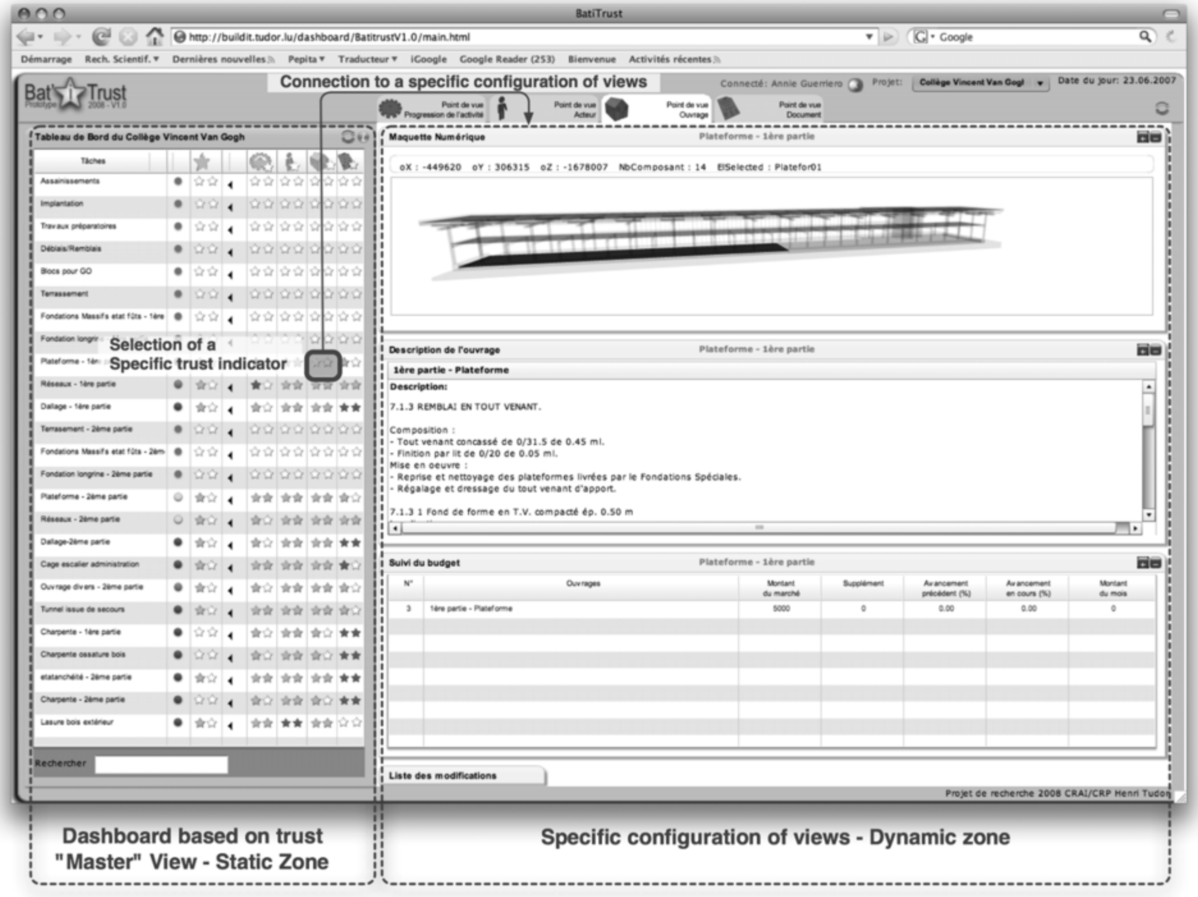

Figure 5 Description of the navigation in the Bat'iTrust prototype

4. Validation

At this stage of this research work, two phases of validation have been carried out:

- The first phase of validation has allowed us to validate the trust criterion thanks to a survey which has allowed confronting them with the practitioners (14 people: architects, engineers, constructors, and construction managers).
- The second phase relies on the use of the Bat'iTrust multi-views interface by some experimental subjects representative from the construction sector.

This second stage was intended to identify the interest of the proposition for supporting the coordination of the construction activity. Seven people (architects (3), architects-researchers (2) and students (2)) tested the prototype on the basis of a scenario close to a real project. The experimental subjects expressed an interest for the dashboard based on trust. They estimated that trust indicators allowed guiding the navigation in identifying the potential dysfunction and that they were reliable to assure the coordination of the construction activity. The post-experiment survey especially demonstrated that the content of the specific configurations of views were adapted to their usage. Some of the experimental subjects identified that the multi-views interface presented a large density of information. Nevertheless it did not appear as a problem possibly because the views included in the multi-views interface look like the paper documents that the subjects use in their daily work.

5. Conclusion

Trust representation is often used in e-business interface to assist the decision processes (e.g. eBay). In light of this observation, this article suggests using trust representation as support for the construction management. It has suggested a connection between the notion of trust and the construction assistance tool and to consider the concept of trust more globally in "*the correct progression of the activity*" (i.e. in the diverse dimensions of the activity and not only the actors). This paper has described a method for measuring and a visualization mode to represent trust. A multi-views interface results from this approach: the Bat'iTrust prototype. This prototype consists in a multi-views interface inside of which the navigation is guided by a trust-based dashboard representing the trust indicators in the construction tasks. It goes beyond the limits of the Bat'iViews prototype developed before, by using the dashboard as a "master view" to guide the user in navigating in the interface.

This result allowed carrying out a first phase of validation. Even if it is not a real-world experiment, this one allowed demonstrating the potential of the representation of trust 1) to assist the coordination of the construction activity and 2) to guide the user in the navigation in the cooperation context. The feedback expressed by the experimental subjects was very positive. At this time of this research, the target is now to propose new applications required for calculating automatically trust indicators in order to soon carry out an experiment in a real context of construction activity.

Acknowledgements

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Index des conférences

ACADIA 2008, Minneapolis, Etats-Unis, p 84
L'une des principales missions de l'association ACADIA (Association for Computer Aided Design in Architecture) est d'organiser et de présenter une conférence annuelle sur des sujets d'intérêt pour la communauté de l'architecture numérique. La conférence et la publication de ses travaux sont un canal important de communication entre les experts dans le domaine de la conception assistée par ordinateur en architecture. Le site de la conférence se déplace chaque année, offrant aux membres la possibilité de voir les installations dans les écoles d'architecture à travers l'Amérique du Nord.

CAAD Futures 2011, Liège, Belgique, p 148
CAAD Futures est une association néerlandaise créée en 1985 avec pour but de promouvoir, à travers des conférences et des publications internationales, la conception architecturale numérique au service de ceux qui s'intéressent à la qualité de l'environnement bâti. Une de ces principales action est l'organisation d'une conférence bi-annuelle qui tourne dans le monde entier.

CAADRIA 2011, Newcastle, Australie, p 18
L'Association CAADRIA (Computer-Aided Architectural Design Research) en Asie favorise l'enseignement et la recherche en conception architecturale numérique en Asie, et compte des membres sur les six continents. Elle organise une conférence annuelle, dont la première a eu lieu en 1996 à Hong Kong. Depuis 18 conférences ont été organisées en Australie, Chine, Hong Kong, Inde, Japon, Corée, Malaisie, Singapour, Taiwan et la Thaïlande.

CDVE 2011, Hong-Kong, Chine, p 152
CDVE (Conference in Cooperative Design Visualisation and Engineering) est une conférence internationale qui promeut les activités de recherche sur la conception coopérative, la visualisation coopérative, l'ingénierie coopérative et leurs applications et ce dans tous les domaines de l'ingénierie.

CIB W78 2010, Le Caire, Egypte, p 50
CIB est un acronyme d'origine française « Conseil International du Bâtiment ». L'association CIB a été créé en 1953 avec comme objectifs de stimuler et de faciliter la coopération internationale et l'échange d'informations entre les instituts de recherche dans le secteur du bâtiment et de la construction engagés dans les domaines techniques de la recherche. Au cours de l'année 1998, l'acronyme a été maintenu mais l'appellation est devenue « International council for research and innovation in building ». Cette association organise tous les ans une conférence internationale.

CIPA 2011, Prague, République Tchèque, p 98
La documentation du Patrimoine CIPA est une organisation internationale qui s'est fixée deux objectifs : suivre les évolutions technologiques et assurer leurs exploitation pour la conservation du patrimoine culturel, l'éducation et la diffusion. Cet organisme organise un congrès international biannuel qui constitue une plateforme d'échange d'idées, des meilleures pratiques et la diffusion de travaux de recherche scientifique.

DMACH 2011, Amman, Jordanie, p 106
La conférence internationale DMACH (Digital Media and its Applications in Cultural Heritage) offre un forum pour examiner et discuter des pratiques actuelles et des orientations futures dans la documentation, la représentation et la communication du patrimoine culturel en utilisant les technologies numériques.

eCAADE 2009, Istanbul, Turquie, p 28, 76
eCAADe (Education and research in Computer Aided Architectural Design in Europe) est une association regroupant des institutions et des personnes ayant un intérêt commun dans la promotion des bonnes pratiques et le partage d'informations en relation avec l'utilisation des ordinateurs dans la recherche et l'éducation en architecture et ses professions. eCAADe a été fondée en 1983. L'organisation organise chaque année une conférence internationale annuelle hébergée dans différentes universités. Cette association a mis en œuvre les archives électroniques CUMINCAD regroupant les publications de recherche dans le domaine de la conception architecturale numérique. Elles constituent une ressource très précieuse pour les chercheurs, les éducateurs et les autres intervenants du domaine.

IBERO CABRI 2012, Lima, Pérou, p 141
Le congrès ibéro-américain Cabri est organisée tous les deux ans pour les chercheurs, les enseignants et étudiants d'Amérique latine, de France, d'Italie, du Mexique, d'Argentine, de l'Uruguay, du Brésil et d'autres, tous intéressés par l'utilisation, l'application et la recherche qui peut être réalisée en utilisant le logiciel de géométrie dynamique Cabri.

International Symposium File To Factory 2009, Crète, Grèce, p 68
Le symposium international rassemble des enseignants des écoles d'architecture en Europe, des architectes/designers et des acteurs de l'industrie de la construction qui exploitent des outils numériques de la conception à la fabrication. Son thème est le continuum du fichier à l'usine ou le domaine de la conception à la fabrication à partir d'un fichier produit dans un laboratoire école ou atelier d'un architecte jusqu'à sa fabrication en usine.

IV 2009, Barcelone, Espagne, p 121, 167
IV 2011, Londres, Royaume-Uni, p 161

IV conférence (International conference on Information Visualisation) s'intéresse aux méthodes interdisciplinaires et à la recherche entre les différentes disciplines de la science, de la médecine, de l'ingénierie, des médias et du commerce. Cet événement l'accent sur la recherche et le développement pour répondre à la demande liée au transfert de l'information à travers le milieu de l'informatique, entre le milieu universitaire et l'industrie dans le but d'échanger autour des derniers développements liés à la visualisation de l'information.

MC 2012, Lyon, France, p 132

Le colloque « Matérialités Contemporaines, Conception, fabrication, perception du cadre bâti » a été organisé pour la première fois en 2012 aux Grands Ateliers Rhone-Alpes. Cette rencontre est centrée sur la question des matérialités appréhendée sous un angle pluridisciplinaire et polysémique. L'objectif premier est de présenter les évolutions et les innovations emblématiques qui accompagnent le renouvellement des paradigmes associés à la construction de notre environnement physique et humain.

SCAN 2012, Paris, France, p 8, 38

Le Séminaire de Conception Architecturale Numérique (SCAN), rendez-vous biannuel de la communauté francophone de l'architecture, est une conférence qui rassemble des chercheurs autour de questionnements portant sur les implications du numérique en conception architecturale. Il vise, notamment, à éclairer l'architecture du point de vue de ses relations aux usages des Technologies de l'Information et de la Communication dans l'intention, d'imaginer, de spécifier et de développer de futurs usages et de nouveaux outils adaptés aux spécificités et aux évolutions de la conception architecturale.

SIGRADI 2010, Bogota, Colombie, p 60

SIGRADI (Sociedad Iberoamericana de Gráfica Digital) est une association qui rassemble des architectes, des designers et des artistes associés aux usages des nouveaux médias dans l'activité de conception. Elle joue en Amérique du Sud un rôle équivalent des organisations similaires en Europe (eCAADe), Amérique du Nord (ACADIA), Asie / Océanie (CAADRIA) et Asie occidentale / Afrique du Nord (ASCAAD). Elle organise une conférence annuelle, qui aborde les dernières applications et usages des technologies graphiques, avec la participation de spécialistes internationaux.

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