Parametric Development of Problem Descriptions

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This paper addresses the development of parametric models in contemporary architectural practice. A parametric model can be regarded as a representation of a solution space and in order to structure this, a description of the problem is required. Architectural design tasks are typically ill structured, the goals may not be defined and the means unknown. Moving from an incomplete problem description to a functional parametric model is a difficult task. In this paper the aim is to demonstrate that through a combination of knowledge acquisition and capture a parametric model can develop from an incomplete problem description. This demonstration draws on existing strands of design theory which are then used to outline a theoretical framework. This framework is then used to examine a case study of a live project and practical examples of the described theory in action are given. The practical observations are the result of a case study involving the author as a participant and observer working with Populous to develop a cladding geometry solution for Lansdowne Road Stadium in Dublin (now know as the AVIVA STADIUM).

1. Introduction

The potential benefits of parametric tools in practice have been acclaimed, while simultaneously they are acknowledged as increasing the time required and the complexity of design tasks [1,2]. The establishment of specialist geometry and modeling groups within architectural practices [3,4,5] suggests an increase popularity of parametric design in architectural practice. The potential benefits of parametric tools are demonstrated by the work of these specialist groups. Parametric modeling has enabled the capture and rationalisation of design intent [4,6]. Building design and construction documentation solutions have been developed using pre-rational and embedded rationale [7,8,9]. Multiple design alternatives can be generated and evaluated in terms of various criteria and better solutions selected [9]. Evaluation methods require different design representations which establish new links with other design disciplines [8,9]. Parametric design has enabled the exploration of complex geometry [10] and deeper exploration of traditional design methods [11]. These examples demonstrate the potential of parametric design through descriptions of detailed stages of design and documentation, but the means for arriving at that final parametric model is often not explored. It is proposed here by systematic study of the process of parametric model development the observed complexity associated with the task can be reduced.

Some of the increased complexity and time required for parametric design can be attributed to the need for the understanding of the technology and learning of technical skills. The cognitive problem of explicitly constructing a solution space or a problem description is considered a more significant issue. Design tasks can be classified by understanding how complete the problem description is. Architectural problems typically can be described as ill structured tasks or even wicked problems [12, 13]. These types of problems consist of unknown goals and means, whereas well structured design tasks have goals that are clearly defined and the possible means for pursuing those goals unambiguously stated.

The process of developing parametric models has been described as "meta design" [14] or "design of design" by Mark Burry. Burry and Maher [15] suggest that everything needs to be considered or known at the outset of a parametric design process. It is suggested here that the opposite may be true, the process of developing a parametric model can begin with incomplete knowledge of the problem. A key part of the process is therefore obtaining knowledge of the problem and using this to structure the problem space. Simon [12] identified that the structure of design problems could develop through continuous modification of the problem space. The task of finding and describing problems as well as solving them has been identified and observed as one of the primary roles of a professional practitioner. Reflection in action [16] is the process of conducting small mental experiments and evaluating the results in order to gain understanding of a problem. Parametric tools can provide an explicit means of conducting reflective tests that enable knowledge acquisition in order to develop and structure problem descriptions.

2. Case study description

Lansdowne Road Rugby Stadium site was highly constrained by boundary conditions (Figure 1 top left). These dictated rights-to-light planning restrictions and horizontal expansion limits defining a possible volume for development. Internally 50,000 seats and a natural grass pitch were required. The combination of these factors along with a desire for a recognizable form led to a proposed design with double curved envelope geometry which acted as a design surface which defined structural roof geometry (Figure 1 right). While the development and control of this geometry was developed parametrically it is not the focus of this paper (see [20] for a detailed technical description and [21,22] for a general theoretical overview of the parametric modeling of Lansdowne Road). This paper focuses specifically on the cladding design task (Figure 1bottom left and right) and how this relates to a body of design method theory.

◀ Figure 1. Top left: Site. Top right: Proposed stadium. Bottom left: Proposed façade. Bottom right: Proposed façade detail.

3. Key themes from theory

In this section a series of key theoretical themes from existing literature are identified and described. These themes focus on the role of knowledge in design. It is proposed that this may form a basis for a theoretical framework for the process of parametric model development. The cladding design task for the Lansdowne Road stadium project is examined in light of these key theoretical knowledge based themes.

3.1 Knowledge

The role of domain or task knowledge (experience or heuristics) is a theme that extends across much of the literature on problem solving and parametric design. Design itself has been defined as a "knowledge based problem solving activity" [17]. Practice based observations have identified that design proceeds in a series of fragmented heuristic episodes [13]. Newell, Shaw and Simon [23] define heuristic as "any principle procedure or other device contributes to the reduction in the search for a satisfactory solution". Successful application of heuristics to design tasks in architecture is dependant on an individual's ability to select a suitable heuristic from a memory of previous design tasks. That memory can only be assembled through experience and the ability to select from it is governed by lateral identification of similar characteristics between the current task and those in the memory.

The ways in which domain knowledge can improve efficiency in design have been identified [18]. Knowledge can be used to reduce the complexity of problems by ruling out ranges of possible solutions. Identification of key parameters (those having greatest effect on design) from the multiple parameters reduces the amount of searching. Further reduction in search can be achieved by knowledge of valid ranges of key parameters.

It is proposed here that parametric tools can provide a representation for capturing existing knowledge and acquiring new knowledge. The process of knowledge acquisition is regarded as equivalent to exploration. Exploration as a method of design has been discussed [17,24,25] as a means of discovering new functionality, constraints and parameters and suggesting how an existing problem description can be adjusted or discarded. The reflective mental experiments observed by Schon [16] are examples of implicit exploration conducted by professionals aimed at gaining new knowledge of a problem. In this paper parametric design is regarded as an explicit means of conducting these kind of experiments.

3.2 Design with knowledge representation

Gero describes how the design process can be intiated by case retrival or through the defintion of a prototype [19]. The starting state is based on analysis of the clients functional specifications and is retrieved from memory or structured based on an existing solution or a solution from a similar problem. Drawing an analogy between the current problem and previous solutions in the designers memory has been described as case based [18], recall [25] and case retrieval [17]. This is consistent with other theories of design where heuristics have been observed in practice [13] to initiate a design process. While some cases may be drawn from human memory others may come from more formal libraries like the repository of design patterns [26,27], or the referents library described by Iordanva [28].

A prototype retrieved from memory is adapted to suit the new condition. The adaptation is based on analysis and knowledge of the new condition, the adapted prototype then becomes the starting point for the design problem. An initial solution can be synthesised and then evaluated to see if it achieves the functions defined by the prototype. This tripartite model of analysis-synthesis-evaluation generates new knowledge of the problem which either leads to reinterpretation of the analysis, synthesis of a new solution or reformulation of function and constraints of the problem. Other cyclic models have been proposed; propose-critique-modify [17] and divergence-transformation-convergence [29], both can assist in developing an initial problem description. The development of the model therefore progresses cyclically and knowledge of the problem increases. At each loop the appropriateness of the described functions and constraints can be assessed. Based on this assessment new knowledge is acquired which is then used to change, omit or add goals and constraints.

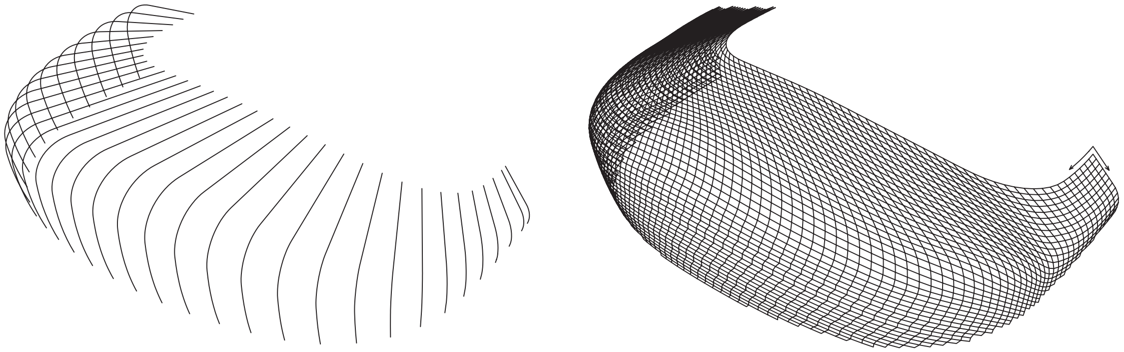
4. Development of Lansdowne Road parametric cladding solution

The cladding design task for Lansdowne Road Stadium can be described as ill structured. The only constant in the problem was the geometry of the underlying structure (Figure 2a). The geometric, material and functional goals of the task were undefined and the means for achieving those goals unknown. The description of the development of the parametric model is organized around a series of iterations each representing a chunk of knowledge acquisition. Each of these iterations can be further decomposed into a series of smaller lower level loops.

4.1. First iteration – initial studies

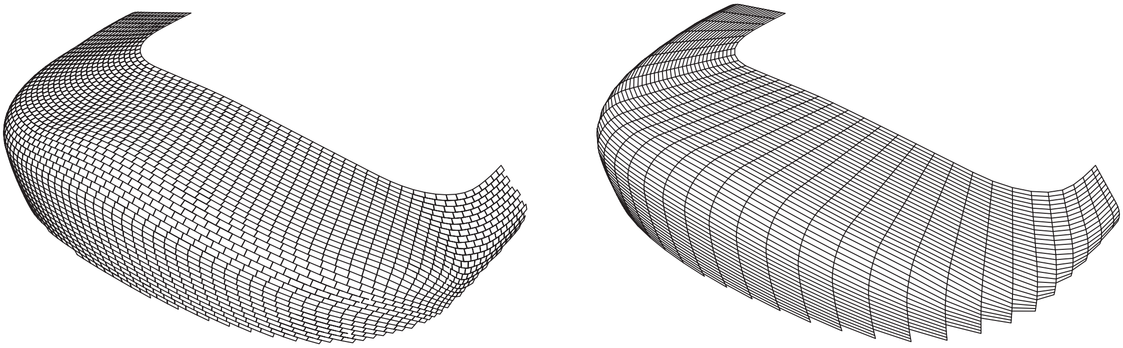
The cladding design began with incomplete knowledge of the problem. All that was known at the outset was that the cladding should cover the underlying geometry. Initially panels were represented as geometric primitives; points and four sided polygons (Figure 2 right). These were located on the underlying geometry which consisted of planar curves, which describe the centerline of each mullion (Figure 2 left). Variables controlling the configuration of the system defined point spacing, starting positions for points, directions for spacing points on the curves and a boolean switch

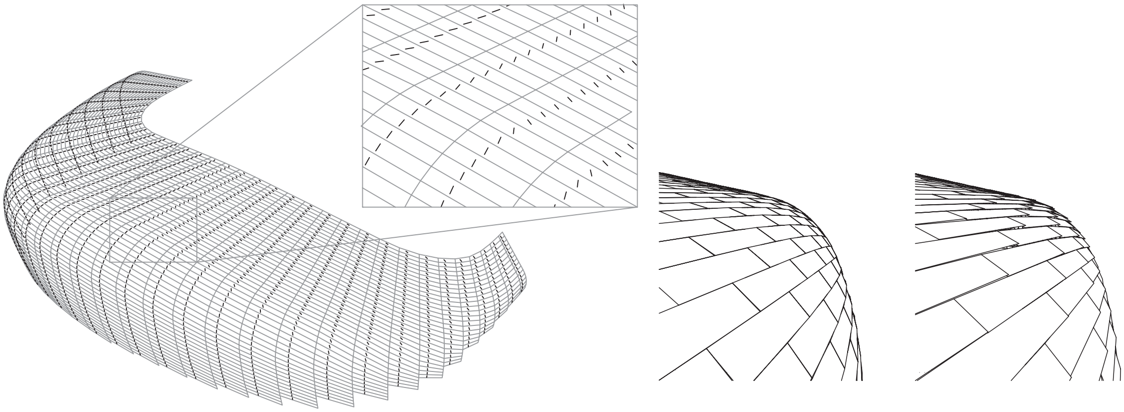
▼ Figure 2. Left: Underlying geometry. Right: Rectangular array of panels over surface



which forced twisted polygons planar. A variety of setting out alternatives were generated (Figure 3) that incorporated both planar and twisted panels (Figure 4 right). Satisfying the initial function was trivial; several alternatives were produced and evaluated by the design team and clients; capturing their knowledge and aesthetic preferences.

▼ Figure 3. Left: Brick bond panel setting out. Right: Ragged array of panels.





▲ Figure 4. Left: Water run-off directions. Right: Visual comparison of warped and planar panels.

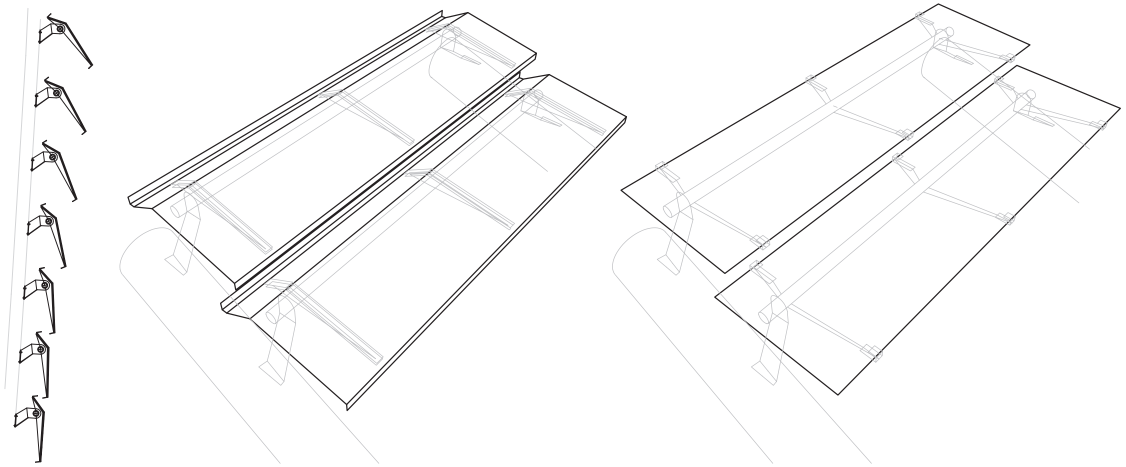
Initially computational knowledge was restricted to what could be achieved with predefined tools with the chosen parametric software. This limited solutions to rectangular arrays of panels. Aesthetic evaluation determined a requirement for ragged arrays of panels (Figure 3 right), computational knowledge was therefore developed to satisfy this requirement.

This initial design phase included developing a means to evaluate the underlying geometry. Two functions were added to indicate; rainwater runoff over a single panel (Figure 4 left) and areas of greatest surface curvature. A line and circle were added to the polygon representing each panel. The panel centroid determined the line start point and circle centre. The fixed length line was defined so it's endpoint lay on the panel and at the lowest possible position, indicating rain water runoff direction. The circle was present only if the out of plane dimension (twist) of the panel exceeded a preset maximum. The final function added to the model at this stage was to layout all panel outlines in one plane with individual identification tags. This was to establish and test some basic methods of processing model information for production. Using this basic functionality parametric models were rapidly produced and examined, this formed the basis for decision making. Decisions made introduced new knowledge and the problem description became clearer. This knowledge was then used or captured as part of the model in the following iteration.

4.2 Second Iteration – manufacturing constraints

Meetings with potential manufacturers introduced specialist knowledge in terms of construction and financial constraints. By proposing solutions based on their experience this knowledge provided a fuller description of the problem, the specificity of which greatly reduced the range of possible solutions. The function of the cladding was defined as a rain-screen, an inner façade would handle full weather proofing of internal spaces. Point and polygon panel representations were replaced with a more complex set of geometric elements representing the panel's components. Two alternative assemblies were proposed by the design team, a glass panel and a folded polycarbonate assembly (Figure 5). Using the geometry of these, parametric models were constructed to produce three-dimensional models for aesthetic evaluation and quantitative information to evaluate for cost, both to deliver and maintain each system. Based on this evaluation an assembly was selected. Selection from two component assemblies was a heuristic step, the decision was informed by fabrication experience, cost and aesthetic preference. This decision imposed geometric constraints on the model, panels needed to be planar, use a standard profile and bracket to fix back to facade structure. These constraints reduced the possible range of possibilities and in doing so further improved the problem description.

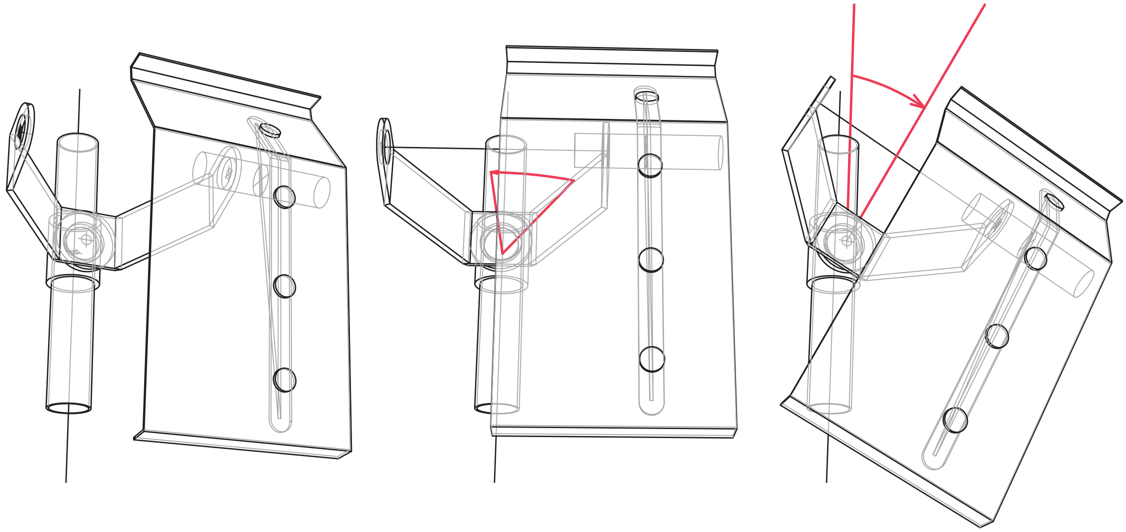
▼ Figure 5. Panel assemblies.

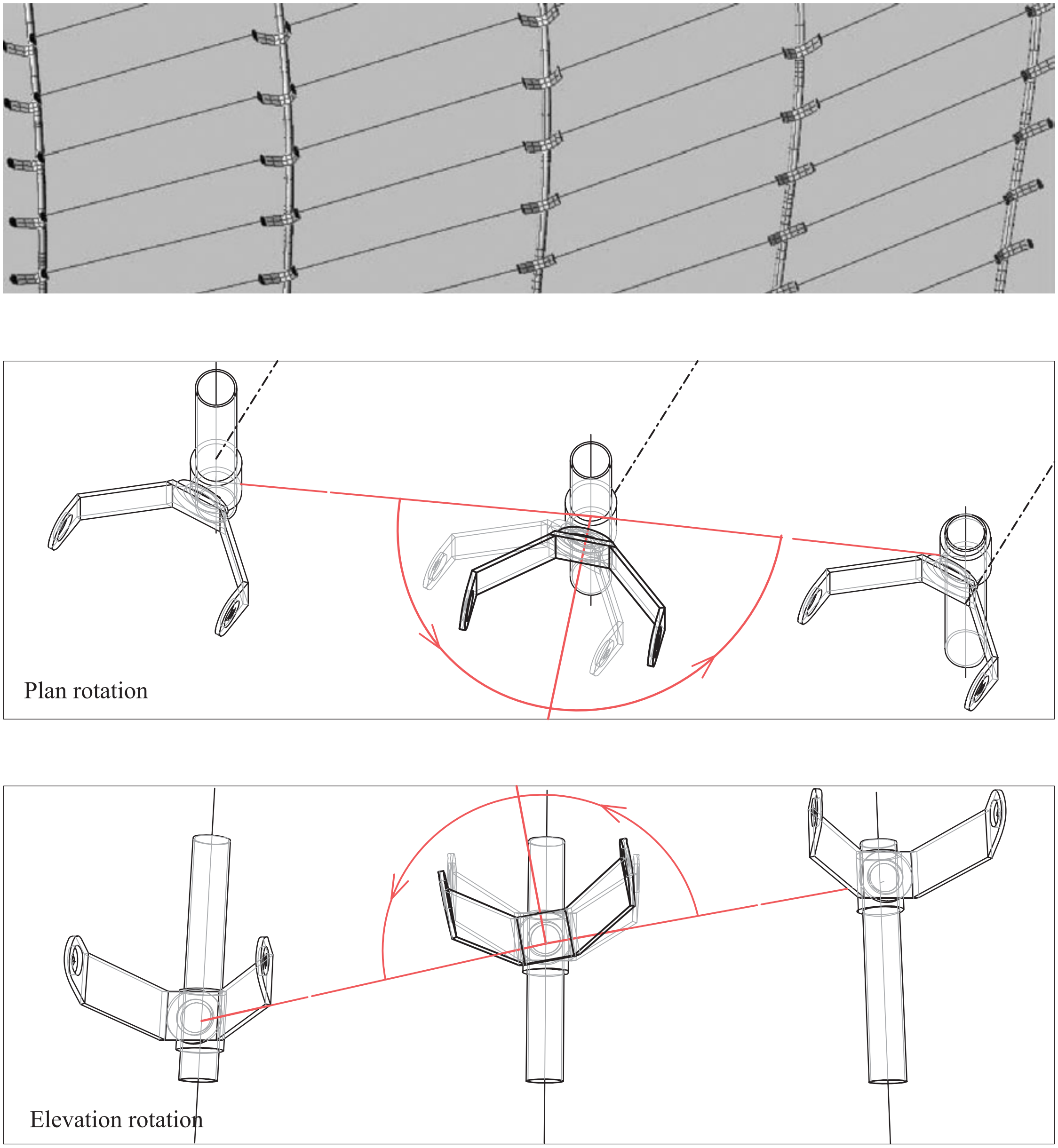


4.3 Third Iteration – developing composition and method

The previous stage had established in detail the function of the cladding design task. The next model development iteration loop involved developing algorithmic knowledge for automating the positioning of a standardised bracket for supporting the panels. The components of panel assembly were known, the method for fixing panels back to mullions was undefined. The function of these fixings was known and financial constraints demanded a standardised system with the ability to support the panels over the double curved geometry. Based on this functional understanding a double arm bracket system was proposed that incorporated two axes of rotation (Figure 6). The way in which the cladding system fits the underlying geometry can be described in terms of the neigbours left and right of each bracket. Two angles are required to position the bracket (Figure 7). Angles are relative to an initial bracket position which is normal to and in the same plane as the mullion. The first angle can be considered a plan rotation (Figure 7 centre) which rotates the bracket around the mullion to give equal angles to left and right neighbours. The second angle rotates the bracket around its face to give equal angles to left and right neighbours (Figure 7 bottom). Given a tangent to the mullion curve and a vector between two brackets the panel plane is defined. To apply this iteratively to all 4000 brackets knowledge was required to develop a computational expression of this algorithm. Algorithms were developed, and then evaluated to see if they could position the brackets and panels on the façade in a satisfactory way. Feedback from evaluation informed modifications to the algorithm. Based on these a new algorithm was produced and evaluated and modified until a satisfactory solution was found.

▼ Figure 6. Double arm bracket rotation axes. Left: Initial position. Middle: Rotation around mullion. Right: Rotation around face of bracket.





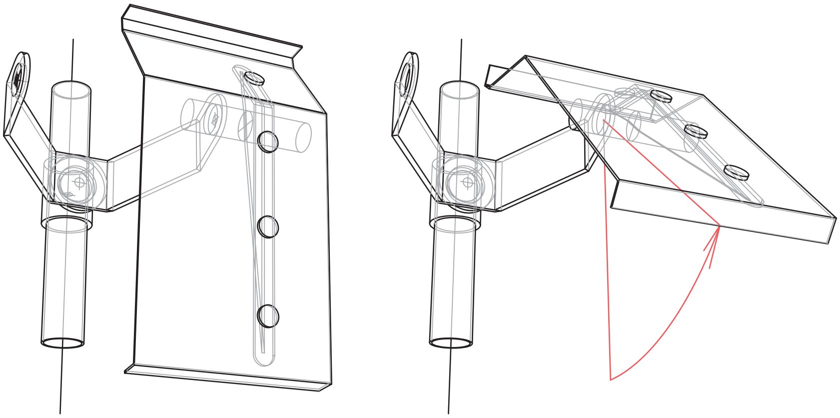
▲ Figure 7. Double arm bracket positioning. Top: Brackets respond to neighbours. Centre: Plan rotation. Bottom: Elevation rotation.

4.4. Fourth Iteration – façade ventilation

At this stage the problem description was quite well defined. The penultimate iteration of the design process involved developing the parametric facade model to provide a way to balance three conflicting criteria; facade ventilation, ingress of wind blown rain and an aesthetic concept. This iteration demonstrates the way a propose-critique-modify [17] design sequence plays a part in practical parametric design.

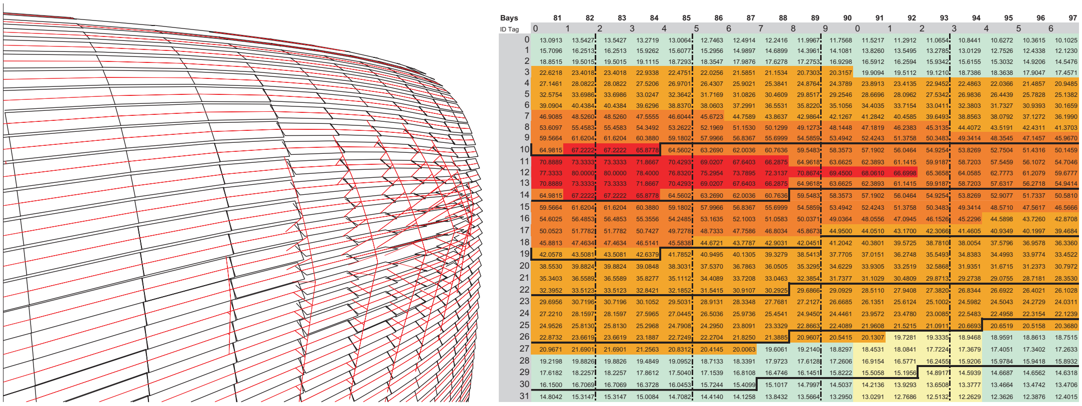
The cladding design had to provide ventilation to intake and exhaust for several plant rooms containing air handling units along the perimeter of the fifth and sixth floors. The proposed cladding panels had a lateral axis of rotation, which allowed the system to operate like a shingle roof. The axis also meant some panels could be fixed in an open position to provide air intake and exhaust for air handling units located behind the facade (Figure 8). Functionally ventilation requirements had to adhere to an architectural concept requiring open panels to blend with surrounding closed panels (Figure 9 left). This concept was initially modeled as an elastic string framework over a small area of the façade that could be "pulled" in certain areas where open panels were required. The elastic nature of this framework meant that the open angle dropped off the further a panel was from the open area. A further functional requirement was to avoid wind blown rain through panel openings around zones containing air handling units.

► Figure 8. Opening panels



The control mechanism was implemented using a spreadsheet that served as a representation of the façade (Figure 9 right). Each cell represented a single cladding panel and contained a rotation value driven by a series of control cells. Control cells corresponded with panels located in front of air handling units, values in these cells were connected to all other cells in the elevation by a series of functions that modeled the required fall off in opening. Cells were conditionally formatted with colour fill to give a visual impression of the blending of panel openings.

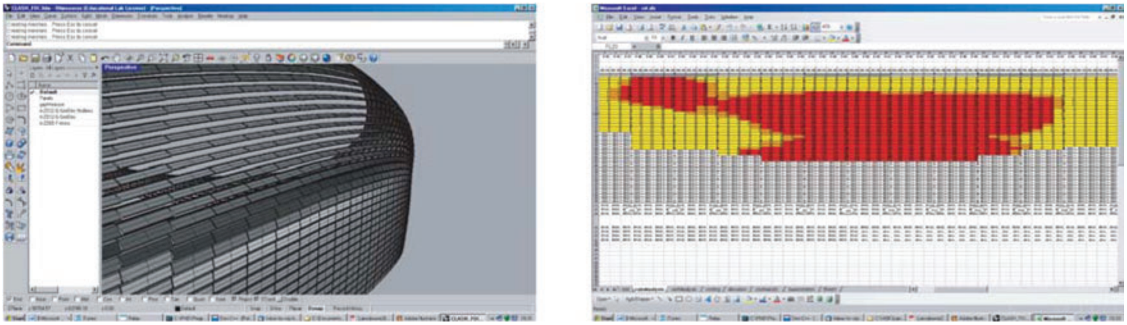
Mechanical engineers provided detailed air venting requirements which were used to determine what set of rotational values were needed. The open area between panels was extracted from the model and mapped into a spreadsheet representing the façade. The total vented area over a plant room could be calculated and compared with the required area. The vertical dimension between panels was mapped into a third spreadsheet representing the façade. Individual cells were conditionally colour filled to visually flag façade areas where wind blown rain would be a problem (Figure 10 right).



Bays	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
ID Tag	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6
0	13.0913	13.5427	13.5427	13.2719	13.0064	12.7463	12.4914	12.2416	11.9967	11.7568	11.5217	11.2912	11.0654	10.8441	10.6272	10.3615	10.1025
1	15.7096	16.2513	16.2513	15.9262	15.6077	15.2956	14.9897	14.6899	14.3961	14.1081	13.8260	13.5495	13.2785	13.0129	12.7526	12.4338	12.1230
2	18.8515	19.5015	19.5015	19.1115	18.7293	18.3547	17.9876	17.6278	17.2753	16.9298	16.5912	16.2594	15.9342	15.6155	15.3032	14.9206	14.5476
3	22.6218	23.4018	23.4018	22.9338	22.4751	22.0256	21.5851	21.1534	20.7303	20.3157	19.9094	19.5112	19.1210	18.7386	18.3638	17.9047	17.4571
4	27.1461	28.0822	28.0822	27.5206	26.9701	26.4307	25.9021	25.3841	24.8764	24.3789	23.8913	23.4135	22.9452	22.4863	22.0366	21.4857	20.9485
5	32.5754	33.6986	33.6986	33.0247	32.3642	31.7169	31.0826	30.4609	29.8517	29.2546	28.6696	28.0962	27.5342	26.9836	26.4439	25.7828	25.1382
6	39.0904	40.4384	40.4384	39.6296	38.8370	38.0603	37.2991	36.5531	35.8220	35.1056	34.4035	33.7154	33.0411	32.3803	31.7327	30.9393	30.1659
7	46.9085	48.5260	48.5260	47.5555	46.6044	45.6723	44.7589	43.8637	42.9864	42.1267	41.2842	40.4585	39.6493	38.8563	38.0792	37.1272	36.1990
8	53.6097	55.4583	55.4583	54.3492	53.2622	52.1969	51.1530	50.1299	49.1273	48.1448	47.1819	46.2383	45.3135	44.4072	43.5191	42.4311	41.3703
9	59.5664	61.6204	61.6204	60.3880	59.1802	57.9966	56.8367	55.6999	54.5859	53.4942	52.4243	51.3758	50.3483	49.3414	48.3545	47.1457	45.9670
10	64.9815	67.2222	67.2222	65.8778	64.5602	63.2690	62.0036	60.7636	59.5483	58.3573	57.1902	56.0464	54.9254	53.8269	52.7504	51.4316	50.1459
11	70.8889	73.3333	73.3333	71.8667	70.4293	69.0207	67.6403	66.2875	64.9618	63.6625	62.3893	61.1415	59.9187	58.7203	57.5459	56.1072	54.7046
12	77.3333	80.0000	80.0000	78.4000	76.8320	75.2954	73.7895	72.3137	70.8674	69.4500	68.0610	66.6998	65.3658	64.0585	62.7773	61.2079	59.6777
13	70.8889	73.3333	73.3333	71.8667	70.4293	69.0207	67.6403	66.2875	64.9618	63.6625	62.3893	61.1415	59.9187	58.7203	57.6317	56.2718	54.9414
14	64.9815	67.2222	67.2222	65.8778	64.5602	63.2690	62.0036	60.7636	59.5483	58.3573	57.1902	56.0464	54.9254	53.8269	52.9077	51.7337	50.5810
15	59.5664	61.6204	61.6204	60.3880	59.1802	57.9966	56.8367	55.6999	54.5859	53.4942	52.4243	51.3758	50.3483	49.3414	48.5710	47.5617	46.5666
16	54.6025	56.4853	56.4853	55.3556	54.2485	53.1635	52.1003	51.0583	50.0371	49.0364	48.0556	47.0945	46.1526	45.2296	44.5898	43.7260	42.8708
17	50.0523	51.7782	51.7782	50.7427	49.7278	48.7333	47.7586	46.8034	45.8673	44.9500	44.0510	43.1700	42.3066	41.4605	40.9349	40.1997	39.4684
18	45.8813	47.4634	47.4634	46.5141	45.5838	44.6721	43.7787	42.9031	42.0451	41.2042	40.3801	39.5725	38.7810	38.0054	37.5796	36.9578	36.3360
19	42.0578	43.5081	43.5081	42.6379	41.7852	40.9495	40.1305	39.3279	38.5413	37.7705	37.0151	36.2748	35.5493	34.8383	34.4993	33.9774	33.4522
20	38.5530	39.8824	39.8824	39.0848	38.3031	37.5370	36.7863	36.0505	35.3295	34.6229	33.9305	33.2519	32.5868	31.9351	31.6715	31.2373	30.7972
21	35.3403	36.5589	36.5589	35.8277	35.1112	34.4089	33.7208	33.0463	32.3854	31.7377	31.1029	30.4809	29.8713	29.2738	29.0755	28.7181	28.3530
22	32.3952	33.5123	33.5123	32.8421	32.1852	31.5415	30.9107	30.2925	29.6866	29.0929	28.5110	27.9408	27.3820	26.8344	26.6922	26.4021	26.1028
23	29.6956	30.7196	30.7196	30.1052	29.5031	28.9131	28.3348	27.7681	27.2127	26.6685	26.1351	25.6124	25.1002	24.5982	24.5043	24.2729	24.0311
24	27.2210	28.1597	28.1597	27.5965	27.0445	26.5036	25.9736	25.4541	24.9450	24.4461	23.9572	23.4780	23.0085	22.5483	22.4958	22.3154	22.1239
25	24.9526	25.8130	25.8130	25.2968	24.7908	24.2950	23.8091	23.3329	22.8663	22.4089	21.9608	21.5215	21.0911	20.6693	20.6519	20.5158	20.3680
26	22.8732	23.6619	23.6619	23.1887	22.7249	22.2704	21.8250	21.3885	20.9607	20.5415	20.1307	19.7281	19.3335	18.9468	18.9591	18.8613	18.7515
27	20.9671	21.6901	21.6901	21.2563	20.8312	20.4145	20.0063	19.6061	19.2140	18.8297	18.4531	18.0841	17.7224	17.3679	17.4051	17.3402	17.2633
28	19.2198	19.8826	19.8826	19.4849	19.0952	18.7133	18.3391	17.9723	17.6128	17.2606	16.9154	16.5771	16.2455	15.9206	15.9784	15.9418	15.8932
29	17.6182	18.2257	18.2257	17.8612	17.5040	17.1539	16.8108	16.4746	16.1451	15.8222	15.5058	15.1956	14.8917	14.5939	14.6687	14.6562	14.6318
30	16.1500	16.7069	16.7069	16.3728	16.0453	15.7244	15.4099	15.1017	14.7997	14.5037	14.2136	13.9293	13.6508	13.3777	13.4664	13.4742	13.4706
31	14.8042	15.3147	15.3147	15.0084	14.7082	14.4140	14.1258	13.8432	13.5664	13.2950	13.0291	12.7686	12.5132	12.2629	12.3626	12.3876	12.4015

▲ Figure 9. Left: Control concept. Right: Control implementation.

In order to construct a solution for this problem an arbitrary configuration of rotation values was defined. The venting areas and wind driven gaps were simultaneously observed to ensure the correct areas were provided while minimising the possibility of wind driven rain. The three-dimensional model was checked to visually judge the smoothness of the transition from closed to open panels (Figure 10 left). Based on this evaluation the panel rotation values were modified in order to create an improved solution proposal. Once an attempt at improvement had been made the new model was again critiqued according to functional criteria, and rotation values modified, this was repeated until a satisfactory solution was reached. It has been suggested [18] that in modifying a solution the designer must select a "focus or context". In this exercise several foci were possible: 1. Achieve correct vent area for a specific plant room. 2. Achieve correct vent area for a block of neighbouring plant rooms. 3. Achieve satisfactory smoothing transitions between blocks of plant rooms. This sub process demonstrates the role of qualitative knowledge. In order to improve the solution it was necessary to develop an understanding for how the different outcomes are interconnected.

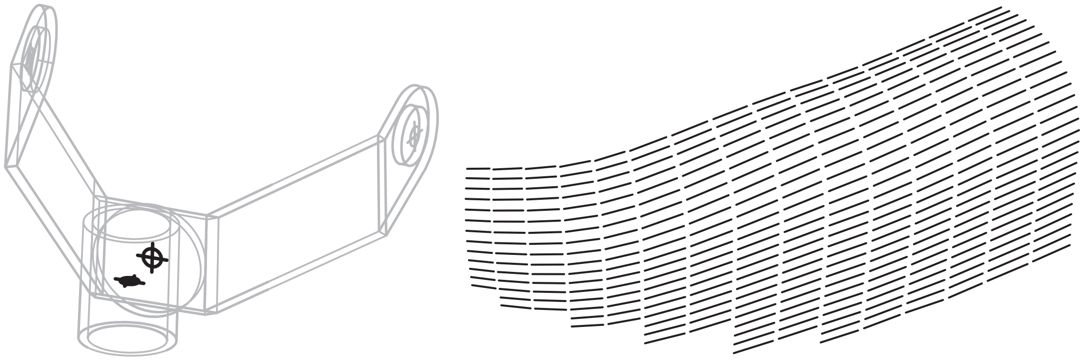


▼ Figure 10. Left: Visual check of panels. Right: Wind driven rain representation.

4.5 Fifth iteration – information issue

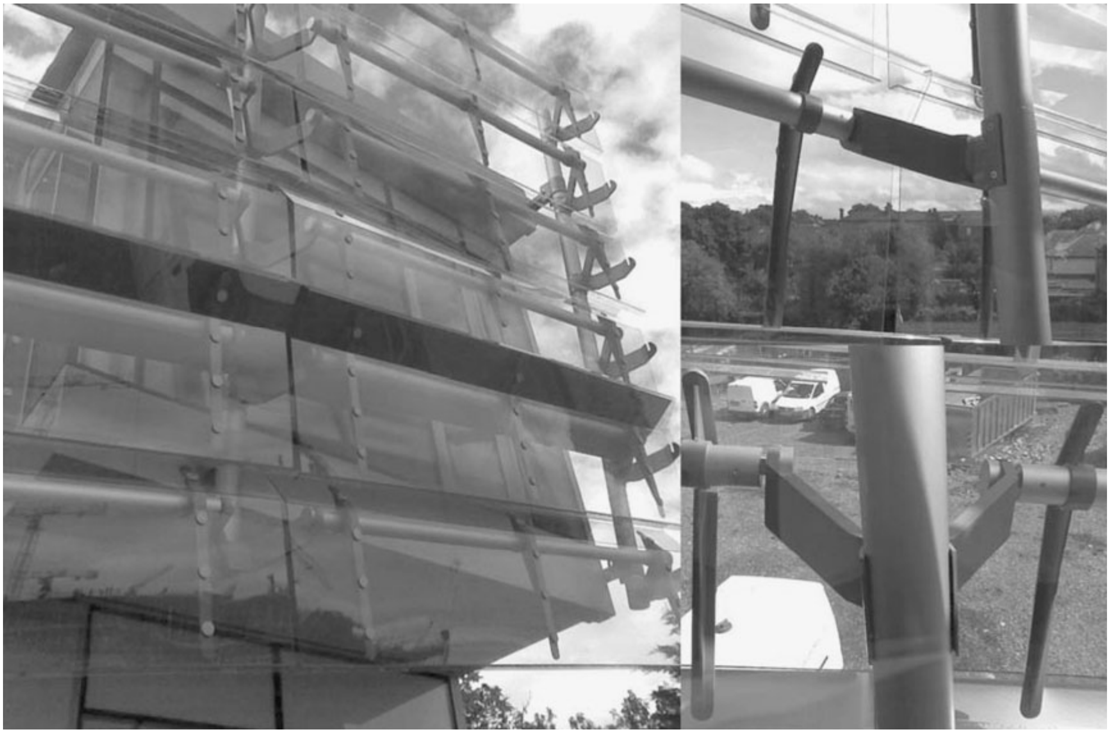
The final iteration in developing the parametric model for the cladding of Lansdowne Road involved the acquisition of knowledge relating to the tasks of the cladding engineers, and the format of construction documentation needed to support this. This aspect of the design process was incorporated into the parametric model to enable design adjustment and instant update of construction data. Contractually the cladding engineers provided a guarantee for the façade, they therefore needed to take responsibility for specifying manufacturing documentation. In order to do this they produced shop drawings and computer models of the façade components which the architectural design team checked. In order to do this they rebuilt the cladding geometry with their own software and incorporated their own details. The architectural design team was able to provide a written description of how to regenerate the geometry. Geometric and numeric data extracted from the architects parametric model and also issued, using this the cladding reconstructed their own model of the façade system.

The representational system devised for the façade ventilation design (one cell per panel spreadsheet) was adopted as the means to convey all numeric data required to configure brackets and panels. This included two angles to orientate brackets and the rotation angle. Additional data was required to configure tolerances on the double armed bracket; the cladding engineers required the horizontal and vertical angles that the rotation bar entered the support. Cladding manufacturers required rationalization of the 4000 varied panel lengths. The parametric model was adapted to group panels into preset ranges, 64 panel lengths were defined. In addition to numeric data three dimensional models were issued. These included centre lines of the rotation bars (Figure 11 right) and a pair of cross hairs, each locating the centre point of a component of the double arm bracket assembly (Figure 11 left). Three-dimensional geometry was used as a checking device by the cladding engineers.



▲ Figure 11. Left: Cross hair and double arm bracket. Right: Rotation bar centre lines.

This final phase of the model development process involved the capture of detailed knowledge from cladding design specialists. This knowledge was not available at the start of the parametric model development but gained in the later stages. In its final form the model is a representation of both design intent and construction method, understanding of which developed with the model. During the development the model provided a means for testing ideas and acquiring new knowledge while also the means of structuring the growing description of the problem space. As problem description detail grew, the solution space decreased until eventually a satisfactory solution was discovered. In June 2008 a full scale mock up of one façade bay was completed on site in Dublin (Figure 12).



▲ Figure 12. Façade mock up

5. Summary

The primary aim of this paper was to demonstrate how a parametric model can develop from an incomplete problem description through process of knowledge acquisition. The cladding design task described here was an ill defined problem with an incomplete problem description, the goals and means were not fully established at the outset. Parametric modeling was the means of acquiring, capturing and representing the problem description as it developed. This demonstrates an alternative view to Burry's [14] and Maher's [15] need for everything to be considered at the outset for parametric model building.

Knowledge was acquired from two main sources. 1. Construction, development, critique and modification of parametric models. 2. Experience of specialists working on the project. As the project progressed the amount of knowledge and therefore model complexity increased, while the solution space was reduced in size. A reduced solution space and well described problem made finding satisfactory solutions more efficient, however other possible solutions may have been overlooked by the nature of the heuristic design process.

The first iteration illustrates starting a design process using assumptions based on incomplete problem descriptions. The task did not begin by retrieval of a similar project from memory or by application a heuristic. Instead the project can be seen as starting as a series of reflective experiments described by Schön [16] however, in this case the experiments were external rather than internal. These were in the form of quickly constructed models, with few constraints that were designed to examine the problem in order to further the limited understanding of it and to potentially change the context. The initial models represented panels as simple polygons; variables provided flexible positioning. Simple evaluation provided the potential to make reasoned changes to the underlying geometry, in this way a problem description began to emerge.

The second phase involved a reduction in the size of solution space by incorporating aspects of specialist manufacturing knowledge. Involvement of manufacturers in the process imposed heuristics which constrained the range of solutions. These impositions reduced the range of possible solutions by constraining geometric options. By applying a known problem structure the size of solution space is reduced. This formalist response to a problem aligns with a more rational view of design such as that described by Simon [12] and Newell *et al.* [23]. However, Simon also proposed that problem structures could develop through continuous modification of problem space. Application of heuristic approach at this stage developed but did not complete the problem description.

The next phase illustrated how the model itself provides a way of developing knowledge. The function of the bracket was known, what was required was the means of expressing this in an algorithm to position panels around the whole building. Defining this was a cyclic process where the problem was initially analysed, the proposed solution synthesised, this was then evaluated by testing it with the known parts of the model. Following iterations are more accurately described as propose-critique-modify [17] as the feedback from the first evaluation informs the way the following proposal is defined.

The penultimate phase provides an explicit example of how propose, critique and modify can be also be applied to find a solution when a problem is well defined. This involved balancing conflicting criteria to provide facade ventilation. The final iteration of the cladding design process illustrates how the working methods or knowledge can become part of the parametric model. The method for communicating information to facade sub-contractors was not known at the start of the design process. However, some basic construction documentation procedures were tested. These were modified once a detailed description of data formats was developed.

6. Conclusions

The case study demonstrates that it is possible to use parametric modeling to develop problem descriptions. This can be achieved with a range of theoretical approaches, which can offer both expansive and reductive methods. Expansive methods rely on exploration to find problem descriptions. Reductive methods apply known problem structures or heuristics (which may be retrieved from memory or a library), these impose constraint, defining a problem description and reducing the range of possible solutions. Any problem description whether discovered or imposed will require improvement, the case study demonstrates how this can be achieved through a cyclical procedure of propose, critique and modify.

On a practical level, developing problem descriptions with parametric design requires working in a way where early models are quickly constructed and treated as disposable. They should be discarded when they do not yield useful results and rebuilt. In this way the rigid structure of the parametric model will not restrict design direction. Later as the problem description becomes clearer it may be possible to develop a more refined and stable model foundation onto which more disposable modules can be plugged in, tested and further developed. Use of placeholders which define simplified versions or approximate guesses (like the initial panel models) will allow modeling to progress with incomplete knowledge. Based on these design decisions can be made, as knowledge becomes available placeholders can be substituted for more precise descriptions.

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