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# Supporting Farmer-Led Irrigation in Mozambique: Reflections on Field-Testing a New Design Approach

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**Abstract:** Smallholder irrigation technologies introduced in sub-Saharan Africa are often unsustainable in the sense that they are not maintained by their users. In contrast, there is clear evidence that smallholder farmers have been developing and expanding irrigated areas. An approach was developed that takes these farmers' initiatives as a starting point to stimulate further irrigated agricultural expansion in central Mozambique, dubbed the PIAD approach (Participatory Irrigated Agricultural Development). The approach was documented through field diaries, participatory monitoring and evaluation. This article presents an analysis and reflection on the design process. Amongst other things, it shows that a crucial difference is the division of roles between users, contractors and irrigation engineers, both in terms of division of responsibilities and in understanding the interdisciplinary connections of irrigated agricultural production. The approach allowed users to be kept in the driver's seat of development while going beyond improving irrigation infrastructure, including agronomic and institutional interventions. Additionally, the results show that technologies are being sustained by their users and copied by farmers in neighboring areas. We conclude that the approach allows for active investment by the users, both in design as well as in project costs and labor, which later results in the improvements being maintained and copied, a clear marker of sustainability.

**Keywords:** farmer-led irrigation; development; design approach; sustainability; Central Mozambique

## 1. Introduction

Investment in water for agriculture has a positive effect on poverty reduction and food security [1]. However, not all irrigation investments in sub-Saharan Africa (SSA) have had positive results [2,3]. Around 2007, a policy debate (re-)emerged about what would constitute the "right type of irrigation" in SSA or the right type of intervention or policy to promote irrigation development [4]. Since 2010 this has led to heavy investments throughout the continent and constituted a strong trend reversal compared to the preceding 15 years or so, which were characterized by very low public investments [5]. The 1970s and 80s also witnessed a wave of investments, accompanied by a growing body of critical scholars that engaged with the theme of irrigation implementation practices [6–10]. With the investments coming to a rather sudden halt in the early 1990s, research on irrigation design implementation practices also became scant.

The renewed investment in irrigation is being pushed by a modernization agenda aiming at increasing food security and reducing poverty [2,11–13]. De Fraiture *et al.* [14] warn that a modernization agenda tends to favor the well-off and that an adequate strategy for investment in and design of water for agriculture is necessary to ensure equitable growth, in order for these investments to have positive effects on poverty reduction in SSA. Woodhouse [15] argues that there are

two contrasting understandings of development of African agriculture and its water use. On the one hand, there is a modernization paradigm that views farming development along a linear path from subsistence to modern agriculture, driven by a technology adoption path. On the other hand, there is the conservation perspective, which nostalgically portrays farmers as caretakers of their natural environment that needs to be made resilient to change. Both views lead to a misunderstanding of the realities within which African farmers operate. Woodhouse [15] argues that a “new paradigm” is needed, which is capable of seeing why African farmers are already investing in irrigation practices.

Rather than centrally planned, state-led irrigation development, localized interactive improvement of irrigation practices seems to offer much better prospects of contributing to lasting production increases and poverty reduction [16]. The existence of a large (and growing) informal irrigation sector provides ample possibilities to engage in such a mode of development.

Despite low formal investments in irrigation, informal smallholder irrigation has been steadily growing. The 80s literature refers to this as “spontaneous” or “indigenous” irrigation, which covers more extensive areas than formal irrigation does, but is disregarded as “unproductive” [17], a stigma that is prevalent even today [4,18]. The suggestion that farmer-led irrigation development in SSA [19] is a fast growing sector covering a larger area than the formal sector, has recently found its way into literature [15,20–22].

For Mozambique, Beekman *et al.* [22] demonstrate that smallholder irrigation in the Manica Province covers about 10,000 ha. An extrapolation for the whole of Mozambique suggests an area of 114,000 ha, while the Mozambican National Irrigation Plan [23] mentions a total existing area of only 9,500 ha in Mozambique. Although the numbers of Beekman *et al.* [22] are estimations, the under-representation of existing smallholder irrigation in the PNI [23] shows that farmer-led irrigation is not recognized.

This article analyzes a participatory approach to irrigated agricultural development (PIAD) as implemented in Mozambique through the Messica Irrigation Pilot Project (MIPP) in 2012–2014. It engages in the current debate on the role of farmer-led irrigation development in SSA and reflects on earlier (particularly 1990s) literature on irrigation design processes and the relationship between irrigation engineers and users. It shows how the approach promotes locally rooted irrigation practices that farmers sustain, expand and replicate.

## 2. Conceptualizing Interactive Design Processes

Several scholars have published on approaches for “interactive irrigation design” and “supporting farmer-led irrigation development” in the 1990s.

In 1993, Jan Ubels & Lucas Horst [10] published an edited book titled “Irrigation Design in Africa: Towards an Interactive Method”, following a decade of debate on irrigation design processes involving a large number of both European and African irrigation engineers. Explicitly from an engineer’s perspective, the book proposes to bring the “social context” into the core of the design process. Their “tuning approach” conceptualizes that farmers’ irrigation practices take shape through interaction with both the infrastructure and the social context. In order to establish the process of tuning irrigation infrastructure to a social context, they propose an interactive design process between engineers and farmers. This implies that “designing no longer becomes a technical exercise executed by engineers sitting behind their desks, but a process of information exchange, discussion, negotiation and collective decision-making about the future use and related technical features of an irrigation system” [10] (p. 99).

The PhD research done by Steven Scheer [24] in 1996 analyzes the design process and communication between engineers and farmers. He concludes that this communication is essential as a learning process for the engineer to capture the essential local knowledge on technical design issues and for farmers to understand the proposed production changes and how these will affect their institutional landscape. He proposes that the communication between engineers and farmers can be formalized in learning cycles with planned engagements between the groups around decision moments. In the case

of Scheer, the planned engagements were formalized around discussion session based on scale models to discuss and visualize the technical operation of the irrigation system. The learning cycles consisted of the efforts by engineers to analyze and reinterpret the problem, adapt the design and model and then re-discuss the results in the next meeting. Meanwhile, the farmers would have discussions with their peers in the community, reinterpret their problem with the insights gained and redefine their solutions, which were then brought back into discussion in the next meeting. This circular process would continue until a feasible and desirable system was decided on and would be repeated again during the implementation and construction.

This iterative learning cycle is also found in the work of Boelens and Dávila [25] about the engagement with “endogenous peasant irrigation development” in the Andes. They analyze how the organizational, normative and infrastructural systems form an integrated whole that they compare to a wheel set in motion by peasant management. External interventions run the risk of “destroying rather than reinforcing” ([25], p. 424) local capacities and maintenance practices when imposing organizational models and disconnecting infrastructural development from ownership (see also [26]. In the context of talking about participation in interventions, Boelens & Dávila [25] imply that outsiders should temporarily participate in locally rooted processes rather than that the farmers should participate in external projects. Central to farmer-led irrigation development “must be their own rationality, their own ‘wheel’, in combination with critical, consensus-based self-analysis by the users, amidst both diverging and shared interests” ([25], p. 427). Collaboration between peasant organization and advisory institutions should take place on openly negotiated terms, investigating whether “collaborating with reciprocal benefits” (ibid.) is possible.

We use these two examples of circular learning processes to conceptualize our approach. We understand that the learning spheres differ between the engineers and farmers, but also that they revolve around the same topic and that formalized communication is necessary for mutual understanding [24]. Simultaneously, we underscore that it is not a circular process, but an iterative process that advances in spirals [25] while a constant renegotiation, redefinition of the problem and redesign takes place until the intervention is finished, and often even beyond.

We separated the irrigation design process into three phases: (1) Problem Identification; (2) Conceptual Design; and (3) Construction & Re-Design. We analyze how the relationship between engineer, users and community gives shape to the design process and its results, in order to understand a design process that aims at having a sustainable impact. For this research, we define sustainable irrigation practices as practices that are sustained by their users and sustainable impact as a lasting impact without need for further external support. In practical terms we look at the following three criteria: (1) farmers investing in their irrigation practices; (2) farmers avoiding and resolving conflicts in a collaborative manner; and (3) farmers replicating irrigation practices in new areas.

In the remainder of this article we analyze the implementation of the MIPP project and its approach to irrigation development and how the approach influenced the sustainability of irrigation practices. We will first give a brief presentation of the approach followed by the MIPP project to set the context before describing three design phases that were followed to reflect on this design process and its use for sustainable irrigation practices.

### 3. Materials and Methods

This article presents the results of systematic reflections on the design process followed in the action research project MIPP (2012–2014) in Central Mozambique, where the authors were also active as engineers in the implementation process. Table 1 demonstrates the timeline for clarification.

**Table 1.** Timeline of the MIPP project.

First Year				Second Year			
1	2	3	4	1	2	3	4
6 months, Participatory Rural Appraisal (PRA) activity at community level; Introduction of the project team, understanding local dynamics, joint evaluation and understanding of production practices and outside linkages	Prioritization exercise; Joint review of the PRA results and ranking of the prioritized intervention areas at community level.	Technical intervention; Problem identification/Design and Construction phase	Participatory project evaluation; Joint evaluation with the project members, Management committee, community and particularly the canal users of the intervention areas.	Prioritization exercise; Re-prioritization of intervention areas at community level.	Start of non-technical activities and assistance in procuring the eligibility requirements for the second rehabilitation round	Technical intervention; Problem identification/Design and Construction phase	Participatory project evaluation; Joint evaluation with the project members, Management committee, community and particularly the canal users of the intervention areas.

Although the project consisted of far more activities, this paper focuses on reviewing and reporting on the rehabilitation and design processes under period three of the time line for both years. The results of the PRA activities (1) and prioritization exercise (2) are presented in the Participatory Irrigated Agriculture Development (PIAD) Guide [26] and in grey literature by students available on request. The Participatory project evaluation (4) forms an essential part of the methodology used to review the technical intervention results. This is further explained below.

The difficulty in reviewing an irrigation design and construction process is that each area of operation and the interactions with each group of farmers are unique, as are the engineer and project team. Consequently, it becomes very difficult to review them in a statistical sense, compare the cases quantitatively or set up the research in such a way that it can be repeated and retested to corroborate the results. We therefore use the research method of Lenzholzer *et al.* [27] on “research through designing” (RTD), which is based on the premise that design and designing processes are an essential part of the research work, while recognizing the uniqueness of both of these. We use their definition of design as the outcome of a design process and follow their suggestion to use “designing” as the activity to reach this outcome. To put this method within the more commonly used methodological frameworks, they further analyze the different knowledge claims: positivist, social constructivism, advocacy/participatory and a “pragmatic” mix of these three to set it against the RTD methods. The advocacy/participatory knowledge claim is particularly interesting in our work as it is based on the involvement of the researcher in action-oriented research with the aim of achieving sustainable change. The means to evaluate and critically reflect on the results are therefore based on qualitative documentations and activities and the use of (peer) reviews of these results. In our case, we use the documentation done by students [28–30] of which some results have been published in peer reviewed articles [22,31]. We use the field reports, the three monthly project reports and project team review minutes, the yearly joint participatory evaluation with the community, and, finally, we use this publication of our results in a peer-reviewed academic journal to guarantee the quality of the interpretations.

The advantage of RTD methodology [27] is that it creates not only new insights for the researchers through critical (peer) reflection, but also knowledge at the community level. A typical question within this knowledge claim, which is also relevant for our research, is “how can the design process be organized around a decision-making process to create commitment and ownership from all actors and reach a more sustainable design?”

We are interested in contributing to irrigation development that is sustainable in the sense that it will have a lasting positive contribution to rural development. Functional irrigation practices exist and persist where strong and fitting connections are forged between human and non-human elements in a variety of ways. These include infrastructural elements, agricultural production practices, marketing of produce, access to agricultural inputs, institutional arrangements, legal and/or normative systems and cultural practices [25,32]. Only in these heterogeneous networks [33,34] irrigation infrastructure does become something that “works”, something that delivers a particular function or value, a “working whole” [16].

Based on this understanding of irrigation practices as networks of connections and of sustainable irrigation development as the sustenance and reproduction of irrigation practices without need for further external support, we study the “crafting of integrative linkages” [35] that make separate elements into “working wholes”. Firstly, we study how interveners and farmers aim to craft these linkages and look particularly at farmers’ investments as an indicator for their assessment whether these irrigation networks will work for them. Secondly, we study how farmers avoid and resolve conflicts with each other, both because we consider it an important indicator for sustainability and because it gives relevant insight in the way burdens and benefits are shared beyond individual gains. Finally, we study whether and how farmers replicate irrigation practices in areas not directly involved in the intervention. We consider this the best indication that the “working wholes” deliver attractive

benefits for farmers and that these constellations of heterogeneous elements can indeed be recreated by farmers without need for external intervention.

The research methodology focused on deepening the understanding of the mechanisms through which irrigation practices are developed, sustained and reproduced. This paper investigates the qualitative elements of how the designing processes take shape and thus form the design outcome, rather than on the amount of area or number of farmers addressed. To this end we collected data in a variety of forms, both quantitative and qualitative, and combined these through content-analysis. This included numbers of farmers, participation in meetings, documentation of discussions and arguments brought forward by different participants, reflection notes of members of the intervention team, reflections by farmer leaders on the development process, registration of costs and labor contributions, local agricultural calendars and marketing practices, mapping and measurement of cultivated areas and canals, and the measurement of basic hydrological data such as stream flows and rain fall. These were used for mixed-method triangulation to gain in-depth understanding of the mechanisms and processes involved [36].

We analyze the design process through the interaction between engineer, users and community during the problem identification and design discussions and between engineer, contractor and users during the construction.

#### 4. Project Background

The Messica Irrigation Pilot Project (MIPP) elaborated and tested an approach to irrigation development aimed at increasing benefits from irrigated agriculture, not necessarily by increasing the irrigation command area. The approach has been documented in a Practitioner Guide under the title “Supporting Farmer-led Irrigation Development” [26].

The approach builds on the following three basic principles:

- (1) It is fundamentally farmer-led, it addresses issues from the people involved and makes all major decisions together with them about what is to be done and how. This also implies that the process is open-ended, without specific improvement activities chosen at the onset;
- (2) It covers the linkages between development of irrigation infrastructure, agricultural development and institutional development;
- (3) It strengthens the innovative capacity of farmers and communities.

The approach starts off from existing processes of farmer-led irrigation development. In the case of MIPP, the intervention area was selected based on an elaborate identification exercise, as documented in Beekman *et al.* [22]. That study observed that locations where farmers were dynamically developing irrigated agriculture without (or with very limited) external support have seven common characteristics: (1) availability of water and land resources; (2) the existence of functional institutions and capacities among farmers for joint organization; (3) availability of suitable water and agricultural technologies; (4) connections to markets; (5) good labor availability; (6) irrigation experience from elsewhere or historic examples in the area; and (7) the availability of (personal) funds to develop agriculture. When starting an engagement with such communities, farmers are usually found to be firmly “in the driver’s seat of development”. The developed approach aims to reinforce this and build on it.

Furthermore, the approach works in three closely interlinked areas: (1) irrigation infrastructure development—creating or managing sources of water, (improving) the design and construction of delivery systems, and operating and managing such systems; (2) agricultural development—all relevant aspects of production including handling of water at field level, processing and marketing; and (3) institutional development—conflict management, strengthening collaboration, establishing and enforcing rules and regulations for water usage and related organizational and leadership developments.

The Messica area, and particularly the village regions of Ruaca and Chirodzo, is known for its farmer-led irrigation development. Across more than 60 small river diversion schemes, over 500 ha of irrigated agriculture were developed since the end of the civil war in 1992. Engagement with the communities started with community-wide meetings and an agreement to collaborate, followed by a process around a participatory rural appraisal (PRA) to structure the discussion with the community about agriculture and potential problems towards growth, and to jointly formulate potential intervention areas.

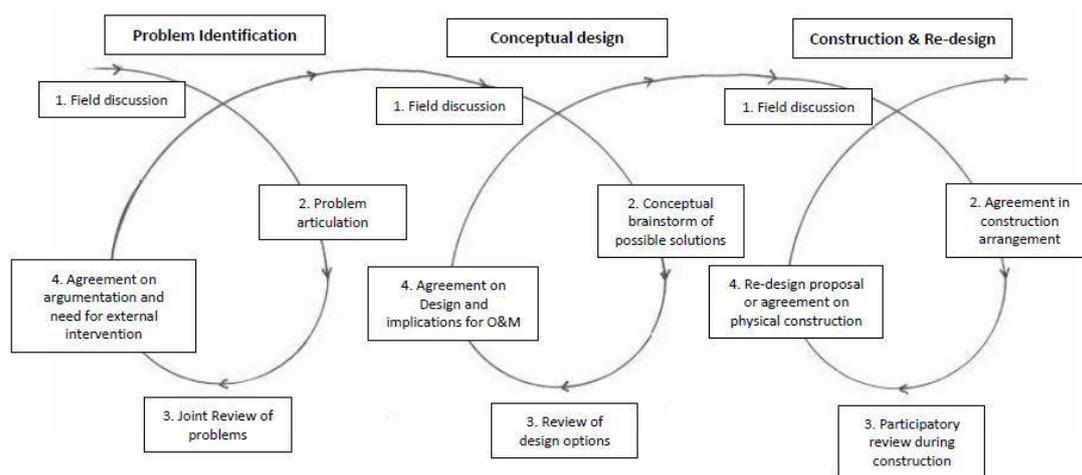
From the PRA activities it was clear that the improvement of irrigation infrastructure was the primary interest. Although the project also tackled other identified problem areas, such as work on irrigation organizations, diversification of production, training and commercialization, this article focuses on the irrigation infrastructural improvement activities.

The project used a two tiered approach to allow for a learning cycle within the project duration. This meant that after the first six months of PRA activities and consequently prioritization of problem areas, two intervention sites were worked on. In the second year, a re-prioritization activity took place in which a further eight intervention activities were identified. This allowed for a joint learning process during the first cycle and an improved approach adapted to local dynamics during the second cycle. The results of the PRA activities are published in the PIAD guide [26] and will not be discussed in this paper. We will however focus on relating and reviewing the designing process and design outcome.

The design process was characterized by three general phases: (1) problem identification; (2) conceptual design; and (3) redesign during construction. These phases were repeated a second time after a joint evaluation with the community. The differences between the two project cycles were not so much in these steps, but in their implementation details.

## 5. Results

In this section we use a chronological narrative following the schematic loops of Problem Identification, Conceptual Design and Construction & Re-design, as shown in Figure 1. For each of the three general phases of the design process, we present an analysis of the mechanisms that influenced (1) farmers' investment; (2) conflict handling; and (3) expansion and replication. These are conceptually summarized in a table at the end of this section.



**Figure 1.** Schematic representation of an irrigation development process focusing on the participatory construction as used in the PIAD approach.

### 5.1. Problem Definition Phase

The activities in this phase were aimed primarily at reaching a joint analysis of current irrigation practices and potential improvements and solutions. Irrigation practices were seen as combinations

of infrastructure, management processes and institutional arrangements around water management, but also included agricultural production processes and market relations. The process aimed at stripping the identified problems to their core so that investments could be limited to solving the problem in ways that could be replicated by the users without further external assistance. An underlying assumption is that limiting the monetary investment will increase the likelihood of replication. For example, we tried to avoid solving organizational problems through infrastructural (*i.e.*, monetary) investments. The interactions and sharing of responsibilities between the engineer, users and the Management Committee allowed for a process where the community would decide on and take responsibility for the choice of project interventions.

When we introduced the project as an “irrigation” project, it created the expectation that it would be a purely infrastructural intervention program. Right from the start, farmers pointed out the need for infrastructural improvements, which for this area were typically dams, improved intakes and the lining of canals. This did not necessarily mean that these improvements would directly address limiting factors in their irrigated production systems. Based on farmers’ inputs, we facilitated discussions between the engineer, users and the Management Committee involving the questions why the suggested rehabilitations were necessary and what they would solve. That is, solutions suggested by farmers were jointly investigated to understand the underlying problem-analysis. The joint analysis often led to a common understanding of the problem and directions in which solutions could be found.

A clear example of such a discussion was in Chirodzo, where the first farmer along a canal had the habit of digging breaches in the side of the main canal at approximately one meter intervals to irrigate the different sub-sections of his field. This resulted in over twenty openings along the main canal for just this one field, each having small leakages when closed. At that time, the canal only conveyed 5 l/s and measurements taken together with the farmers demonstrated that this practice caused 40% of the water loss over a distance of 50 m. This situation could be solved through infrastructure, rules, or a combination of these. Infrastructurally lining the canal and building a single concrete canal offtake would entail a substantial investment, while clearer rules and a better enforcement could equally well solve this problem institutionally. This is an example of a situation that can be resolved both infrastructurally and institutionally. Discussions and analyses often started with farmers’ requests for infrastructural interventions, while digging deeper into the problem analyses helped in finding alternative solutions, often with better prospects for local replication without external intervention.

The most persistent discussions revolved around the intake structures, their design, operation and maintenance. Initially, farmers presented their rehabilitations (typically portrayed as converting local constructions made of bush materials into concrete walls and metal gates) as a way to increase the flow into the canal. However, joint visits to several intakes along the same mountain stream, provided a clear picture of the interdependence of these systems; an increased diversion upstream could negatively affect irrigation practices downstream and disrupt (implicit) agreements about sharing along the stream. Despite their wishes to divert all the water from a stream into their canals, farmers did not succeed because the existing intake structures made of stones, bags and mud would always have leakages and let water pass downstream. This joint observation was combined with our suggestion that if the goal was to increase the water availability at field level, there were various other options to achieve this, including agreements on rotational water usage and on methods of abstracting water from the canal, maintenance practices, and lining of porous canal stretches. These could be even more effective than extracting more water from the stream, while having less negative impact for downstream users.

From these discussions it also emerged that intake-improvement was desired, because the local constructions wash away several times during the rainy season. The hydrology of the mountain streams in this areas during the rainy season is characterized by frequent dry spells (periods without rain that can last for weeks) followed by storm events [31]. These dry spells make irrigation essential, despite the average rainfall resulting in rainfall surplus, while the storm events lead to massive increases in water flow (from base flows rates of ca. 40 l/s to peak flows of over 2000 l/s) and

consequently wash away the intake structures through sheer force of the river. Discouraged by the frequent storm events, users would often not rehabilitate the intake until after the rainy season thus not irrigate during a considerable part of the year. This period coincides with the time of the year in which tomatoes, the main cash crop of the area, have the highest market value. The few farmers that retained access to water saw clear cash gains. Upgrading the intakes to permanent structures would secure an extra irrigated production season for many additional farmers, therefore providing a good argument for returns on investment and facilitating additional investments by farmers themselves.

Repeatedly questioning the reason why users perceived a proposed intervention to be necessary was important, because it helped clarify their problem analysis. This resulted in a process of pushing back and forth between the farmers, trying to externalize their management problems through infrastructural interventions by the project, and the engineer, when seeing issues as essentially rooted in the management or regulatory domains. By inviting the Management Committee to be part of this process, a triangular relationship was established between the engineer, the farmers (or users of the targeted system) and the Management Committee, representing the community as a whole. This helped to see that water losses at scheme level could often be reused downstream and therefore are not necessarily a loss.

### *5.2. Conceptual Design Phase*

The conceptual design phase is a continuation of the discussions around problem definitions, in which initial ideas for possible solutions have already been mentioned. However, it is also a distinct phase, as the focus changes from analyzing existing problems to thinking towards solutions. This involves comparing and weighing different solutions with varying combinations of institutional and physical changes.

In the MIPP project, we decided to work with existing institutional structures; for example, in a step to become eligible for a technical intervention, the users of a canal had to formulate their Operation and Maintenance (O&M) plan. This is a first step to consolidate existing informal structures in water management and, during the design discussions, is taken further by questioning the observed operational practices. Hence also clarifying decisions on roles and responsibilities during the design and construction phases, which reflect the local customs of participation in maintenance work and endeavors to strengthen existing conflict management mechanisms through these efforts.

The design phase is an iterative process that in mainstream design processes is often separated in pre-design, design and final design, with further refinements in the details of each step. Often, there is a bias towards the infrastructural design outcome. However, next to issues related to specific irrigation systems, we also continued discussions around water distribution at catchment scale. In Chirodzo, this resulted in an agreement on water distribution between canals. We also used transect walks along the canal to discuss internal water management issues, which led to a short training on the use of siphons to extract water out of the canals.

An important discussion during this phase concerned the roles and responsibilities during construction and usage. As it became clearer what type of structures were to be constructed and what sort of materials were needed, it became possible to discuss who would be doing what during the construction. It was furthermore clarified what the project and engineer, through the contractor, would do and how the users would contribute. This discussion involved the local contractor, the users, the Management Committee, and the engineer. The results of the discussion (besides the design drawings and principles, also the payment of the local contractor and the contributions to be made by the users) were put into a three-party contract, read aloud, and signed by the engineer, the contractor and the Management Committee. This contract enforced an early discussion of the users' willingness to invest. What did they perceive as a fair and worthwhile contribution? This focused on the sourcing of local materials (sand, stones) and the provision of labor. Later, as the work progressed, the users frequently tried to renegotiate the contract, aiming to reduce their responsibilities, often claiming to misunderstand the terms. The Management Committee played an active role in these discussions

that generally resulted in re-agreeing on the terms of the contract. By entering in such discussions, the relationship between the engineer and users was maintained and deepened, even if they showed that the renegotiations were not based on misunderstandings, but rather were attempts to push tasks towards the project.

In this phase, the design discussions were held between the engineer, the users and the Management Committee. A local contractor was appointed by the users and the Management Committee to implement the constructions, while also supervising the labor contribution of the users. The contractor was paid by the project to ensure that the engineer had some form of control over the quality of the work. Working with a contractor from within the community had two important advantages with regard to possibilities for the replication of the work. Firstly, it strengthened the local capacities for construction and repairs of hydraulic structures. Secondly, it forced the engineer to use procedures and materials that were within the boundaries of what was locally considered feasible.

Taking functioning irrigation practices initiated by farmers as a starting point, was another effort to increase the changes of replication by other farmers. Both their original initiative and the improvements under the MIPP project were within the capabilities of the users, institutionally, financially and technically.

For the irrigation systems taking their water from small mountain streams, the improvement of the intake consisted of small concrete structures combined with the lining of the first meters of the canal. The design discussions were relatively easy and revolved around the location of the intake structure and the operational effects of the distribution boxes. These were all within the realm of local construction methods and not very different from existing water management practices.

In the case of irrigation systems that take their water from a bigger river, the option of a concrete diversion structure would become technically complex and very costly because of its need for a deeper and bigger foundation, in some case requiring heavy machinery. This would very likely not be replicable by farmers and local contractors. As an alternative, the construction of gabion weirs (mesh wire boxes filled with rocks) was proposed. This was met with skepticism, partly because it would be a semi-permeable diversion structure, but also because it was an unknown construction method. In the subsequent year, after the first gabion weir had proven itself during the rainy season, this design became the preferred solution by farmers in other systems, suggesting that it also has a realistic chance of being replicated after project completion. This also demonstrates the importance of learning cycles.

### *5.3. Construction and Re-Design Phase*

The start of this phase is marked by the signing of the three-party contract. While actual construction activities started soon after the signature, the design activities did not stop. The construction phase is an integral part of the iterative process of designing, where new insights acquired during construction lead to re-design. Even after extensive discussions and visualization, designs remain very abstract and difficult to understand for most farmers. Especially if the proposed solution is one that users are not familiar with. It became clear that the hydraulic principles are difficult to convey without a constructed example.

The process of re-designing during construction proved an important element in the appropriation by the farmers of the improvements. It allowed for learning cycles through practice and the close interaction with the contractor and engineer clearly put them in the driver's seat. An example from a canal in Chirodzo was about the location of the emergency spillway. During the conceptual design phase, the users and the Management Committee had been very adamant about placing it some distance from the river diversion weir to prevent tampering by passersby. But during the construction and after a rain event, the water flow became unmanageable and it was consequently requested that the spillway would be relocated to the diversion weir. Active response and facilitation of these types of change during the construction had the clear effect of users taking ownership of the process. In later stages, they were more vocal and active in small adaptations of the construction work. They even

went so far as buying bricks as a group in order to facilitate their own contribution of stones. This is a distinct sign that they were willing to invest financially in the system.

Although this case nicely demonstrates the willingness to invest and likelihood of replication, it was also a learning moment in the relationship between the engineer and users. Initially, the engineer was eager to facilitate and adapt the conceptual design during construction to accommodate the farmers' input, but as the construction progressed, more and more of the system was literally cast in concrete, which limited the technical options still available for adaptations. Because of his eagerness this first construction was not the best technical solution possible for that situation, although it does work and is being maintained by its users. This was amended in the second year, when a clearer responsibility to guarantee sound technical construction was given to the engineer.

In the case where the first gabion weir was constructed, there was less discussion about the exact dimensions and characteristics of the intake structure, probably because the technique was not well-understood by its users at first. During the construction phase, discussion centered on the organization of the construction, particularly the contribution from the users. Skepticism towards the design of the weir resulted in low preparedness to participate in the collection of the local building materials and provision of labor to assist the contractor. It required a lot of energy from the project team and the Management Committee to keep the work going. At a certain moment, we had to stop the operation, withdraw the contractors, and indicate that they would only return once the users reorganized themselves and provided the local materials, as agreed upon in the contract. For the project, this was an important principle to guarantee replicability of the design, as willingness to invest during the project was an indication of its replicability and the farmers' understanding of the need for further investment after the project departure. The project was prepared to abandon this construction, if the users would have continued to refuse their labor contributions. The users claimed that the work and materials required were too much and not well understood earlier in the design process. Nevertheless, the users did resume the work and the contractors returned to finish the construction. After the structure had been tested during rain events, the opinion on its characteristics changed dramatically and proved the original claim to stop the work to be incorrect. Firstly, surviving the first heavy rain events disproved the faulty perception of the structure as weak, and secondly, the permeability of the structure was qualified as positive, as enough water would be diverted into the canal while guaranteeing that it would also continue to flow in the river. The effect of this change in perception was very noticeable in the second year of the project, as groups of farmers specifically asked for the construction of the gabion weirs, knowing the amount of labor required from them. Where the construction of the first weir had taken four months, the last two weirs of the same size took on average three weeks, without any discussion about input of labor or materials.

The learning cycles inherent in this iterative approach not only functioned as a form of project management, but also proved supportive of efforts to strengthening local conflict management techniques. The role of the Management Committee was particularly important as a body of arbitration for larger community level issues, while the user contribution of labor and materials during construction allowed for discussions on other regular maintenance work. These discussions were used to finalize the O & M plans as a part of the handing-over ceremonies. The willingness to invest in this type of construction was clearly shown in the second year, where users of other schemes pushed for gabion constructions, both in the conceptual design phase and during construction. The same readiness to invest was also very obvious in the first improved scheme in Chirodzo, when a year later its users had taken additional erosion protection measures to secure the intake-structure without further (outside) technical input or financial assistance.

#### *5.4. Summarizing the Results*

Table 2 summarizes the relation between the actions taken in the three design phases and the sustainability indicators.

**Table 2.** Summary of the design process in relation to the sustainability indicators.

Sustainability Indicators	Project Phases		
	Problem Definition	Conceptual Design	Construction
(1) Willingness to invest	<p>Prior investment by farmers as pre-condition for project support and as a form of measuring willingness to invest. Besides monetary or material investments, joint formulation of an O&amp;M plan also counts.</p>	<p>Discussion around roles and responsibilities; What do farmers expect as project contribution and what are they willing to invest? Engagement in these discussions indicated a willingness to contribute and proved an important sign. The relative ease of these discussions around user contributions was a clear indication of a high willingness to invest.</p>	<p>Involvement of users in the design and re-design discussions proved an important form of investment, resulting in clear ownership of the results. Farmers investing in additional erosion protection measures by themselves were clear indications of this ownership and their willingness to invest.</p>
(2) Avoid and resolve conflicts	<p>The organization of the discussions between engineer, users, and the Management Committee allowed scaling-up to river basin level, and comparing and finding joint solutions with different systems. On several occasions, this setup resulted in input on how the users and the Management Committee could resolve conflicts between canals, but also in resolutions of disagreements on responsibilities in project execution.</p>	<p>Discussions held between engineer, users and the Management Committee proved important in reflection on design requirements, but particularly in setting rules for construction. Registering agreements in a contract and involving the Management Committee as a higher local level authority, facilitated resolution of conflicts and renegotiation efforts by users in a later stage.</p>	<p>The construction phase reinforced the rules setting that assisted in conflict resolution by forcing users to deal with local (labor) management problems occurring during this phase. The involvement of the Management Committee was important in strengthening the inter-canal and inter-project problem resolutions. The variety in type and number of problems that had to be resolved in the first (more) as compared to the second (less) year was an indication of the increased capacity to resolve and avoid conflicts.</p>
(3) Replication to new areas	<p>Focusing on how an intervention resulted in improved production practices, allowed to limit monetary investments. Reducing the monetary investments increased the likelihood of replication, whereas reflecting with the users on their arguments for the necessity of investment increased the capacity for replication elsewhere.</p>	<p>Revolving the conceptual design around improvement of local practices resulted in solutions that were replicable elsewhere. Involving local contractors and artisans in the design discussions increased capacities and the likelihood of replication.</p>	<p>The demonstrations and the different project cycles were important and proved to be necessary for the interventions to be replicated. The clear demand and fast construction of the gabion weirs in the second project phase were indicative of its replicability.</p>

## 6. Discussion and Conclusions

In this article, the analysis of the design process starts with the problem definition phase, but the design process heavily builds on the six months of preceding activities. This process has already been described elsewhere [22]. The joint PRA activities created opportunities for the community's involvement in the decision making processes, while it formed a basis for the project team to get to know the area and increase understanding of the local context. Whether the same outcome could also have been achieved if we had taken less preparation time is difficult to evaluate in hindsight, but the observation that it is a time-consuming effort for participatory processes to become meaningful and create ownership [35] is not a new one. Relationships where trust and mutual respect could grow formed the basis of a mutual learning process, which consisted of cycles of defining problems, exploring solutions and translating these into workable methods and procedures. With each winding of the spiral, both the depth of understanding the problems and solutions grew, as well as the extent of mutual trust.

This learning process occurred in relatively small cycles in collaboration with water user groups on specific interventions, while larger cycles were observed in relation to larger communities, both geographically (traversing the whole project area) and temporally (extending over the whole intervention period of 2.5 years).

For the learning process involving specific interventions with water user groups, we recognize the following three main mechanisms at work. In the first place, there were discussions at each specific intervention site about the nature of the problems experienced and the characteristics of the solutions. The initially expressed wish for a concrete weir and a lined canal without the community being able to explain how this would improve their production clearly demonstrated the influence of a modernization mindset. Morris [17] describes how in policy circles modern technology is strongly favored over existing production practices, which are portrayed as "inefficient" and "traditional". This modernization mindset also proved to be strongly present among water users, sometimes mixed with (implicit) arguments for a particular solution because it would require less labor for construction and maintenance, and/or the wish for greater control over water flows. The project team aimed to direct such discussions at looking for cost effective solutions that could both financially and technically be carried out by the water users. Sometimes, these were long and winding discussions, spread out over months of interactions in the three design and construction phases.

Secondly, the investment by water users formed an important point of interaction. During the construction phase, the required hours of labor and volumes of locally available construction materials, such as sand and rocks, became a very real and tangible issue. The project required a substantial contribution, which initially was not something the water users wanted to supply. It proved however to be a good indicator of participation and understanding. On several occasions the refusal to contribute indicated that certain aspects of the design and construction plan had actually not been understood.

Thirdly, the contractors and the way in which they were hired played an important mediating role between the project engineer and the users. While the engineer had the responsibility to ensure technically solid designs, the users had other desires for the designs too. The contractor often became an intermediary in these processes. The choice to work with local contractors ensured that translating the ideas from the users to the engineer was never a problem. It consequently proved important that the contractor was paid by the project, instead of directly by the users, as this allowed for a clearer accountability towards the engineer, thus facilitating the intermediary role.

For the learning process in the overall project area and throughout the project's duration of 2.5 years, at least three mechanisms played a role. Organizing the project in two rounds of activities in two consecutive dry seasons contributed substantially. In the first round of activities, two canal systems were improved. This first season was concluded by an evaluation of the project, conducted jointly between project team and the users. This resulted in modifications in the project's engagement with the community and users. Firstly, the selection of specific intervention sites became more demand-driven. It was decided that only canal groups that had actively demonstrated an interest in

improving their irrigation by writing the “operation and maintenance regulations” of their canal were eligible. The project team considered this a demonstration of the minimally required capacity of the users, to convene and agree on regulations. Secondly, the two diversion weirs built in the first year provided a base for discussions and allowed other users to comprehensibly determine what specific intervention they wanted, and why. The technical examples proved informative, but particularly the contractor hired to do the new construction better understood what was required of the users. Consequently, he was an important link between the engineer and the users, explaining how the proposed design worked and what would be required from the users during construction. These reflect a learning process on the content of the technical options. Thirdly, the two intervention processes served as examples of the project’s capability to deliver on its promises and that this would only be done if farmers also delivered on their promises. This reflects a learning process regarding the relational aspects. As a consequence of these three mechanisms, the design and construction processes simultaneously went much faster and extended over bigger areas.

The MIPP project, through its the PIAD [26] approach, made an effort to step away from top-down implementation of blueprint technical solutions and formulaic approaches to institutional building, in order to make space for locally crafted solutions, rooted in ongoing learning processes. This created opportunities for steering towards solutions that could be operated, maintained and copied by local actors without the need for further interventions. However, there is always the risk of also turning this PIAD approach into a formulaic blue print method when the participatory process to capacitate, learn and co-develop sustainable solutions is not taken seriously. In the end it remains dependent on whether a more conventional project staff “believes” in the participatory process as a means to get better and quicker results out of a project. However, we conclude that the PIAD approach as applied in the MIPP project demonstrates that it is not so much about the capacities of the engineer/project staff, as it is about creating space for farmers involvement in the designs, insisting on contribution in the construction and strengthening the existing institutions.

The ability and willingness to use and expand irrigated agriculture was seen as the main indicator of sustainability. We conclude that the sustainability of a project intervention can be assessed during the project cycle by looking at three aspects: the willingness of farmers to invest in the proposed intervention, their capacity to reach collective solutions supported by the participatory processes and whether the intervention is copied by other farmers. We further conclude that the process of the users and engineer co-designing can create sustainable outcomes in terms of solutions that can be realized by farmers themselves. Such processes are relatively time-consuming (and expensive) when implemented at a small scale, but have good prospects for scaling up when actively building on the learning processes. This is in line with the conclusion by Innocencio *et al.* [3] that large-scale projects focusing on small-scale interventions might lead to better results when allowing for active involvement of the farmers in all the design and construction phases. Ultimately, we conclude that this approach allows for active investments by the users, both in design and in project costs and labor, which subsequently results in the maintenance and replication of the improvements, a clear marker of sustainability.

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